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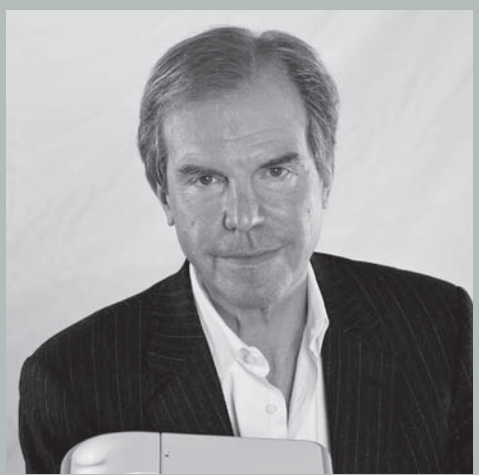
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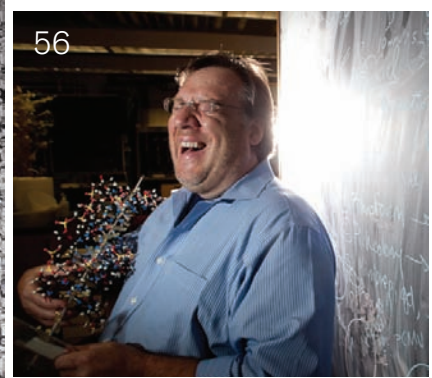
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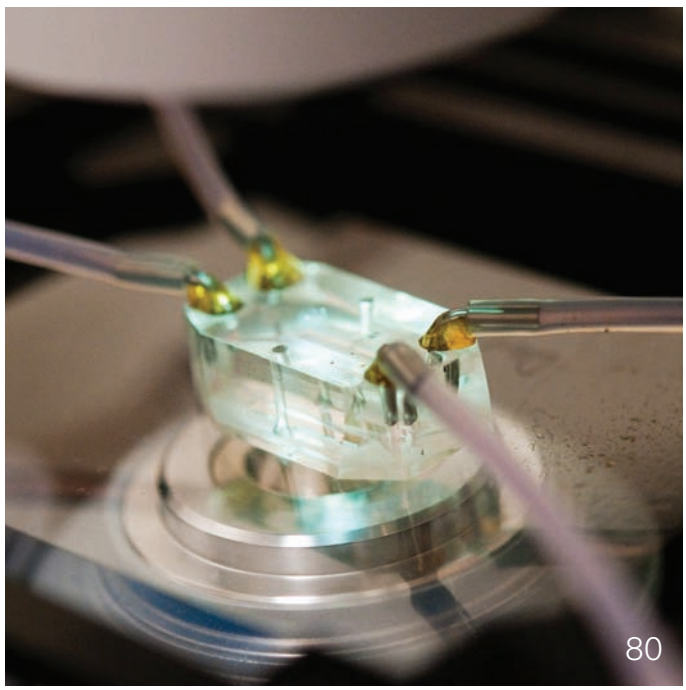








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feedback

"10 Emerging Technologies," May/June 2012

"Of all the innovation going on in this country, Timeline? Really? Shame on you."

Alec LaLonde, Salt Lake City, Utah

THE RAVAGES OF TIMELINE The May/June issue featured our annual list of the year's top technology breakthroughs ("10 Emerging Technologies"), and as usual, readers took issue with some of our choices. The inclusion of Facebook's Timeline seemed to be a particular point of annoyance. **Alec LaLonde** of Salt Lake City, Utah, wrote: "Please elaborate on how it will 'have the greatest impact on the shape of innovation in years to come'? Your entire supposition is based on the collection of data for the purpose of advertising—how does this at all help its users? To them, Timeline is merely an (often unwanted) restructuring of a user's homepage. And I suspect the lofty idea of a Web 'permanent record' is merely a side effect of maximizing data collection, and not at all the primary goal. Facebook's much-hyped IPO makes this decision especially disconcerting. Of all the innovation going on in this country, Timeline? Really? Shame on you."



May/June 2012

Other choices drew much more praise, such as the faster Fourier transform—an effort by a quartet of MIT researchers to create a new algorithm for processing data. "If I had to lay a bet as to which of these 10 technologies will have the most effect over the next five years, I would put my money on this one," wrote **ptmmac** in an online comment. "We are talking about sending more information with less bandwidth, and many other algorithms being speeded up by this new shortcut. We are living in the age of the algorithm—this is a big deal."

LENDING AND MISSPENDING The U.S. Department of Energy's loan program is "in shambles," wrote *TR* editor David Rotman in "Can Energy Startups Be Saved?" Because of diminishing government help, Rotman concluded, the best bet for small energy companies will be to partner with the large companies they might once have hoped to make obsolete. "This sounds trite," responded **dnwdfw**, "but maybe companies need to grow organically, without federal intervention. The vast majority of startups do fail, and that birthing process actually weeds out the weak and marginal, allowing the ones with the right DNA to thrive. It's called the market, and we need to let it work and stop letting the feds pick the winners based on politics and cronyism."

Sault, another online commenter, took a different tack: "DoE loans are problematic nowadays because of gridlock in Con-

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gress concerning the budget and frivolous investigations conducted solely for political reasons. U.S. solar companies are hurting because China is dumping solar panels on the world market at unfairly low prices due to currency manipulation, meager wages, unsafe working conditions for employees, zero government oversight, and massive overt and hidden subsidies. Let's get rid of fossil-fuel subsidies and make those companies pay for the damage their products cause to people's health and the environment."

CHARM: OFFENSIVE? Is Siri, the new iPhone's personal assistant, really breaking new ground in artificial intelligence? Or does it use wit and charm to cover up its shortcomings? *TR*'s online editor, Will Knight, tackled this question in "Social Intelligence" and found that AI has a long way to go—though he found Siri's charm irresistible anyway. **Alexanderm** responded: "Does the charm of Siri's personality provide lasting benefits, beyond the novelty effect? Anecdotally, several colleagues have said they're a bit tired of smart-alecky replies."

"Back in the early '80s," wrote **cvmichael**, "I attended an AI conference and Nicholas Negroponte opened his talk by saying AI is 95 percent artificial and 5 percent intelligent. That said, Siri is fun to use and much better than Vlingo and Evi, at least for now."

BELIEVE THE HYPE Our photo essay on Tesla's manufacturing floor ("Building Tesla") got some readers debating whether Elon Musk's high-end electric vehicles were worth all the hype. To which **flipd** responded: "I keep hearing that same tired argument from critics that if a car isn't selling 200,000 units, it's a failure. The Corvette sold only 13,000 units in 2011. It's an expensive sports car that not everyone can afford, but they keep making them, don't they? People will pay a premium to have something a normal car won't do. In the case of the Corvette, it's speed and handling. With the Volt, it's the technology and the idea that for your average commute you will hardly ever have to fill up with gas. The Tesla is a no-brainer, in my opinion. Less than a Corvette, more luxurious, almost as fast, and you don't have to pay for gas." tr





ENERGY

Lesson Learned

The Fukushima disaster should make nuclear energy safer than ever, says Jacopo Buongiorno.

On March 11, 2011, one of the strongest earthquakes in recorded history struck Japan's northeast coast. The earthquake and the tsunami that followed killed more than 20,000 people and caused over $200 billion in property damage. The tsunami also disabled critical safety systems at the Fukushima-Daichii nuclear power plant, resulting in damage to its fuel rods and a large release of radioactivity.

Scary though the accident looked and sounded in the media, its radiological consequences are negligible. Nobody has died from radiation exposure. The Japanese government evacuated tens of thousands people from the area surrounding the plant to avoid radiation doses that would have had no measurable effect on their health. On the other side of the world, as the accident was still unfolding, Germany chose to shut down its nuclear plants and replace their output with energy from renewable sources *(see "The Great German Energy Experiment," p. 50)*, a decision comparable to giving up driving because a friend crashed a car on a dangerous road. German nuclear plants are among the best-operated in the world, and seismic and tsunami risks in Germany are practically nonexistent. The decision seemed to be more the result of politics and public fear than of logic.

Most countries using nuclear energy were more rational. The U.S., the U.K., France, China, and South Korea, among others, studied the Fukushima accident closely so that they could reduce the likelihood of similar events at their own plants. These countries restated their commitment to the safe and secure development of nuclear energy as a way to combat global warming and ensure energy independence. A number of countries with young nuclear energy programs, such as the United Arab Emirates, Turkey, Vietnam, and Poland, did not significantly alter their plans after Fukushima.

The consensus now is that the tsunami protection system at the Fukushima plant was "underdesigned." When a nuclear plant loses off-site power, it needs on-site AC and DC power sources to activate safety systems and read instrumentation. At Fukushima, those backup sources were in poorly protected rooms that were overwhelmed by the large waves of water.

Protecting on-site AC and DC power sources in waterproof, fireproof rooms is the simplest way to defend nuclear plants against natural events such as floods, fires, hurricanes, and tornadoes. U.S. plants are already well equipped thanks to measures taken after September 11, 2001. Following the disaster in Fukushima, the U.S. nuclear industry took voluntary action to strengthen protections against natural disasters. The U.S. Nuclear Regulatory Commission recently formalized requirements for extended protection against such events in current and future plants. Nuclear energy will emerge even safer after Fukushima, just as it has after previous accidents. It will continue to produce clean and reliable power for the benefit of humanity. tr

Jacopo Buongiorno, associate professor of nuclear science and engineering at MIT, works on thermal hydraulics and the safety of nuclear power plants.

SOCIAL NETWORKING

Data Dystopia

Zeynep Tufekci says Facebook's power over our social lives comes with great responsibility.

Dystopias in the 20th century came mostly in two flavors: the imposing surveillance state, as depicted in Orwell's *1984*, and the stupefying pleasure dome, as in Huxley's *Brave New World*. What if these were not separate nightmares? The real threat could be surveillance in the service of seduction rather than punishment.

Facebook is so successful because it helps us fulfill the urge to remain connected to one another. That urge has led about a billion of us to provide a single company with imprints of a sizable part of our social lives *(see "What Facebook Knows," p. 42)*.

As a social scientist, I'm terribly excited by this data trove, because it's a great resource for studying the human animal. Emerging "big data" sources—Facebook is one of the best—have the potential to contribute to our understanding of society. But this information has uses that go beyond targeting ads. Though the prospect doesn't seem to faze Facebook users so far, it could be used to target civic, political, and social messaging in ways that are unhealthy for democracy.

Political campaigns, for example, now encourage voters to connect with their Facebook apps or pages, which can access in-depth data about not just a person but his or her social networks and interactions. This creates opportunities for profiling at unprecedented precision and scale. I am waiting for the first wave of vicious negative political campaigning on Facebook. (Most of us might not even notice it, since it could be narrowly targeted to a receptive niche, or even to individuals.)

The way Facebook uses its collected data can influence our social interactions. Facebook's news feed does not show all updates, or even the most recent, but rather what

NICK REDDYHOFF



Facebook thinks will make you click or comment. News-feed algorithms create spirals of reinforcement for certain behaviors. The details are secret, but reverse-engineering shows that Facebook thinks photos generate more engagement than text; updates with them are featured more prominently, leading to even more engagement. Even without explicit instruction, people will undoubtedly pick up on these cues and start posting ever more photos. In other ways, too, Facebook may be guiding how we socialize. Perhaps cheery posts get more prominence. Perhaps we will one day learn of a suicide following a brief, cryptic status update that no one responded to because Facebook downgraded it on people's news feed upon judging it not to be the kind of post that generates clicks.

I do not claim there are easy answers to the questions Facebook raises. Any algorithm for the news feed would have its downside. But the questions are important because Facebook occupies an important civic niche. Decisions about how it uses its hoard of data, what it makes public, and how much access it gives political and corporate campaigns will affect us all. We need to be talking not just about the potential of this awesome data store but about the power the company has and the ethics it upholds. tr

Zeynep Tufekci is an assistant professor at the University of North Carolina and a fellow at the Berkman Center for Internet and Society at Harvard.

BIOLOGY

Safe Science

Lessons from nanotechnology can help synthetic biology mature, says David Rejeski.

Synthetic biology—the science of engineering systems from biological organisms or parts—could have a significant impact on our lives. Numerous products based on this technology, including bioplastics, pesticides, biofuels, and drugs to treat diabetes, cholera, and cancer *(see "Biology's Master Programmers," p. 56)*, are already on the market or close to it.

That march from lab bench to market is under scrutiny from venture capitalists, politicians touting the new bio-economy—and the usual naysayers. This last group warns of scientists "playing God" and fears that terrorists could exploit the technology for cheap bioweapons. Friends of the Earth and other organizations have called for a moratorium, insisting that capitalism yield to the precautionary principle.

This scenario is familiar to anybody with a memory going back 10 years. Nanotechnology was once discussed in similarly hyperbolic terms, with scientists talking up its Earth-saving capacities and opponents warning that self-replicating nanobots could devour the planet. The fervor has since cooled, and the global nanotechnology market is expected to reach $30.4 billion by 2015, according to Global Industry Analysts.

When the public is confronted with new technologies, trust is volatile, and mistrust can have lasting effects—witness European consumers' rejection of genetically modified foods. We should learn from what helped nanotechnology break free of the hysteria.



As nanotechnology matured, federal spending on research into its environmental, health, and safety risks increased—from $38 million in 2006 to an estimated $103 million in 2012. In 2008, the National Science Foundation and the Environmental Protection Agency invested $38 million to establish two centers to address nanotechnology's environmental implications. A similar commitment should be made for synthetic biology. There are complex, legitimate questions about how synthetic organisms can be contained, whether they can survive in the environment, and whether their genes will transfer to other organisms. These questions will not be answered quickly or cheaply, but answering them will open doors to future markets.

By shouldering some of the responsibility, the synthetic-biology industry can also help build public trust, as DuPont did in 2007 by working with the Environmental Defense Fund to develop a risk management framework for nanotech. The press could also help by better communicating the real issues rather than, for example, suggesting tenuous links between the small amateur biotech scene and the H5N1 bird-flu virus. Finally, synthetic biology would benefit from a coherent, long-term national strategy and better international coördination. The Obama administration's National Bioeconomy Blueprint, released in April, is only a start.

In his provocative 2000 essay "Why the Future Doesn't Need Us," computing pioneer Bill Joy claimed that robotics, genetic engineering, and nanotech were making it possible to construct "technology that may replace our species." We are still here, but we shouldn't let our guard down. tr

David Rejeski is the director of the Science & Technology Innovation Program at the Woodrow Wilson Center in Washington, D.C.



The Planetary Experiment

What is Facebook doing with its unprecedentedly large network?

Amid all the chatter about Facebook's recent initial public offering of stock—much of it determinedly superficial (was the IPO bungled by its underwriters?); some of it substantive, at least for investors (what was an appropriate valuation for the company?); and a quantum clarifying (see Michael Wolff's review "The Facebook Fallacy" on page 70, which argues that the company lacks "the big idea")—left unspoken was the general assumption that the social network was monstrous.

Facebook is disquieting for several reasons: because it is the largest network ever to be controlled by a single company; because its corporate values (insofar as they can be guessed from its technologies and mission "to make the world more open and connected") suggest a commitment to a "radical transparency" that is new to human affairs; and because, as we entrust more of our personal information to its databases ("dumb fucks," the company's chief executive, Mark Zuckerberg, once called his early customers), we are learning that we are its principal assets. (To learn how Facebook hopes to use its 900 million users to market products and services, see "You Are the Ad," May/June 2011.)

The planetary scale of Facebook's network, its ideology, and its store of data have suggested an irresistible idea to the company's technologists: that they should conduct experiments upon humanity in real time. So far, those experiments have been benign, but the fact that they are being conducted at all has the jarring, science-fictional strangeness of the truly novel.

This issue's cover story, "What Facebook Knows" *(p. 42)*, reveals the group conducting the experiments: the Data Science Team, whose 12 researchers form "a kind of Bell Labs for the social-networking age." The feature's author, Tom Simonite, writes that the members "apply math, programming skills, and social science to mine our data for insights that they hope will advance Facebook's business."

The group is led by Cameron Marlow, who is quick to minimize the impact of his work on the larger world. "Marlow says his team wants to divine the rules of online social life to understand what's going on inside Facebook, not to develop ways to manipulate it. 'Our goal is not to change the pattern of communication in society,' he says." But Simonite is skeptical: "Some of his team's work and the attitudes of Facebook's leaders show that the company is not above using its platform to tweak users' behavior. Unlike academic social scientists, Facebook's employees have a short path from an idea to an experiment on hundreds of millions of people."

Simonite provides some examples of the tweaks possible. They are blameless, if spooky. But as a publicly traded company, Facebook is now dedicated to returning value to its investors. Its interests are not those of its users.

The frontispiece to the original, 1651 edition of Thomas Hobbes' *Leviathan* was an etching by Abraham Bosse showing a crowned giant emerging from behind a hill: his torso and arms were composed of more than 300 figures, turned inward. It is an apt visual metaphor for the emerging commonwealth of Facebook.

Mark Zuckerberg has sometimes compared Facebook to a nation. (If it were one, it would be the third most populous on the planet.) At the moment, we have no theory of how such a virtual commonwealth should be governed, or what obligations the crown has to its people. But write and tell me what you think at jason.pontin@technologyreview.com.

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CHARLES DHARAPAK/AP

CEO David Vieau explains one application of A123's technology to President George W. Bush at the White House in 2007.

ENERGY

What Happened to A123?

Once the rising star of the clean-tech industry, the advanced battery maker faces an uncertain future.

When A123 Systems went public in 2009, things could not have looked better.

A123 boasted advanced lithium-ion battery technology, developed at MIT, that promised to popularize electric cars by making batteries more powerful, safer, and longer-lasting. The company had factories capable of producing millions of batteries per year. Between the IPO, private funding, and tax credits and grants from the government, it had raised about $1 billion. Its stock price nearly doubled shortly after the IPO as investors clamored for a piece of a hot clean-tech company.

Three years later, A123's situation looks very different. The company's shares, once worth more than $25, trade for less than $1. A123 loses money on every battery it sells, and after years of increasing losses, it's desperate for capital to stay afloat. What happened?

For one thing, A123 depended too heavily on a single customer, the electric-car maker Fisker. When Fisker failed to bring



“It allows you, as a parent, to monitor kids’ driving behavior in real time. And if your kid is SMS-ing while driving, you will be able to log it—and even remotely disable the phone.”

Raz Dar, a manager at AT&T’s business incubator in Ra’anana, Israel, talking about a prototype cloud-based system for monitoring teen drivers.

its Karma sedan to market in time, it cut back orders for batteries.

But A123’s problems also reflect the challenges facing many startups in highly competitive energy markets. Not only is it expensive to commercialize and manufacture energy-related products—A123 has spent well over $300 million on equipment and other capital expenses over the last three and a half years—but it is also risky. In A123’s case, the company appeared to scale up too quickly. As it rushed to ramp up production for Fisker, it produced some defective battery cells, leading to a costly recall and replacement program.

A123 has contracts to supply batteries for several brands of vehicles over the next few years, including GM’s upcoming Spark. The company says it can become profitable eventually—if it can raise enough money to keep going until those supply contracts kick in over the next couple of years—and that the contracts will allow it to achieve the volumes necessary for exploiting economies of scale.

That path appears daunting. Andrea James, an analyst for the investment bank Dougherty & Company, estimates that A123 needs to sell nearly 50,000 electric-vehicle battery packs a year—more than a tenfold increase over last year’s sales.

She also says that the company must make technical advances to become profitable. Says Jeff Dahn, a professor of physics and chemistry at Dalhousie University, in Halifax, “A123 has a very impressive battery system. It can provide very high power, and it works really well at low temperature. But unfortunately, it doesn’t have all the ingredients that a successful lithium-ion battery technology needs to have.” In particular, Dahn says, A123’s battery lacks a low-cost method of energy storage.

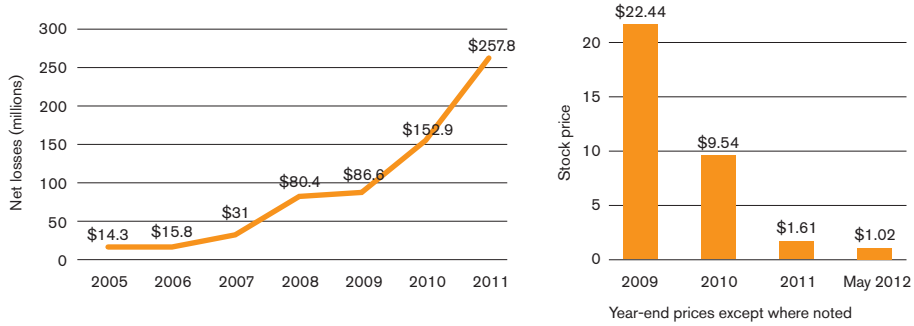
A123 is drumming up business in other markets; for example, it’s selling batteries to help stabilize the electrical grid. But it surely will remain heavily reliant on electric cars, whose sales overall have been disappointing. To make matters worse, it’s not clear whether A123 will hold on to EV makers as customers. Automakers need to feel sure a company will be around for many years to fulfill warranty obligations, and A123’s financial troubles could scare some of them off.

EV sales have been sluggish because the cars cost up to twice as much as their gas-fueled equivalents. Batteries—which sell for over $10,000—are one of the biggest reasons, even though automakers are buying them for less than it costs to make them. A123 talks about lowering its costs as it produces batteries in greater numbers, but this may not do much to make electric vehicles cheaper; it would just help A123 by finally allowing it to make money on what it sells. Those hoping for a revolutionary technology that will make electric vehicles affordable may need to look elsewhere.

—KEVIN BULLIS

Mounting Losses and Falling Expectations

A123 has never been profitable, and its net losses have grown every year since 2005. That’s partly because it costs more to make its batteries than A123 can sell them for.





TO MARKET

Secret Connections

TrustChip

COMPANY KoolSpan

PRICE Undisclosed

AVAILABILITY Now

No ordinary memory card, the TrustChip can upgrade any phone to make super-secure encrypted calls and data transfers—which would usually require expensive specialized mobile devices. Making encrypted connections requires the phone on each end to have a TrustChip installed in its memory slot. Apps can then route calls and messages via the chip and its 32-bit encryption processor. The product is aimed at organizations, like security services and banks, that worry about eavesdropping.

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“There are two kinds of people: Some people who say, ‘I’m not going to give you my data at all unless you give me a million bucks.’ And there are a lot of people who say, ‘I don’t care, I’ll give it to you for little.’”

Bernardo Huberman, an HP researcher who is creating a market to let people realize some of the value in their personal information.





TO MARKET

Home Power Supply

Owners of the electric Nissan Leaf in Japan can now use their cars as backup power supplies for their homes. Nissan’s Leaf to Home system converts DC power from the car’s battery to AC power compatible with home appliances. Once connected to a household electrical panel, it delivers power through existing wiring to plugs throughout the house. The Leaf stores enough electricity to supply an average Japanese home for about two days.

Leaf to Home

COMPANY Nissan Motor

PRICE ¥330,000 ($4,200)

AVAILABILITY Now, in Japan

COMPUTING

WHAT’S THE NEXT INSTAGRAM?

In the wake of Facebook’s billion-dollar purchase of the mobile photo service, video-sharing apps are jostling to become the next big thing.

Sharing photos from mobile devices has become hugely popular, but many mobile-app developers are already moving past still images to video. Free video-sharing apps like Viddy and Socialcam have quickly gained users who are clamoring to make little flicks on their phones and send them to friends online.

With this in mind, I reviewed several of these video apps. The best ones let you give your videos a creative edge by adding effects such as filters and background music.

Even if you don’t create a prize-winning film, you’ll have fun developing your inner auteur.

—RACHEL METZ

Socialcam

AVAILABILITY: Android and iPhone

SHARING: Facebook, Twitter, YouTube, Posterous, Tumblr, Dropbox, e-mail, and SMS

Unlike most other apps, this one doesn’t limit video length. Before you shoot, you select one of Socialcam’s filters, such as the flashback-inducing “Grunge” or the *Tron*-like “Electronica.” After you’ve shot, you can pick a soundtrack from a variety of cheesy prerecorded tunes. Socialcam is indeed very social: the app has more ways to share videos than any other one I tried. So many choices can make the app’s interface feel too crowded, though.

Cinemagram

AVAILABILITY: iPhone only

SHARING: Facebook, Twitter, Tumblr, and e-mail

This addictive app lets you create hauntingly beautiful animations that combine video with still imagery. After you take a short video, Cinemagram will show you the first frame of the clip. You then use your finger to shade in the portion of the screen you want to animate; the rest of the image will remain static. If you shoot a video of friends dancing and highlight only their shadows, you’ll create a still shot of your friends with their shadows boogying over and over.

Viddy

AVAILABILITY: iPhone only

SHARING: Facebook, Twitter, YouTube, Tumblr, e-mail, and SMS

Viddy is devoted to clips no longer than 15 seconds. It’s full of features, such as a handy on-screen sound meter that lets you keep an eye on volume. When you’ve finished taking a video, you can change its look by adding a filter; each also has a soundtrack that you can adjust or turn off. I liked the ability to adjust the strength of a filter, which is useful if, say, you’re using the production pack Snoop Dogg created for Viddy but want just a hint of the smoky haze layer it typically imposes.

Tout

AVAILABILITY: Android and iPhone

SHARING: Facebook, Twitter, e-mail, and SMS

Tout also limits you to 15-second videos. Its no-frills setup makes it very simple to quickly share clips with friends. Tout has no filters to choose from, and you can’t use the iPhone’s digital zoom. You just shoot your video while a little on-screen clock counts down the seconds to zero. After recording a clip, you can add a note to describe it and choose a social network to share it on or e-mail a link to your friends. You can easily watch other users’ creations.

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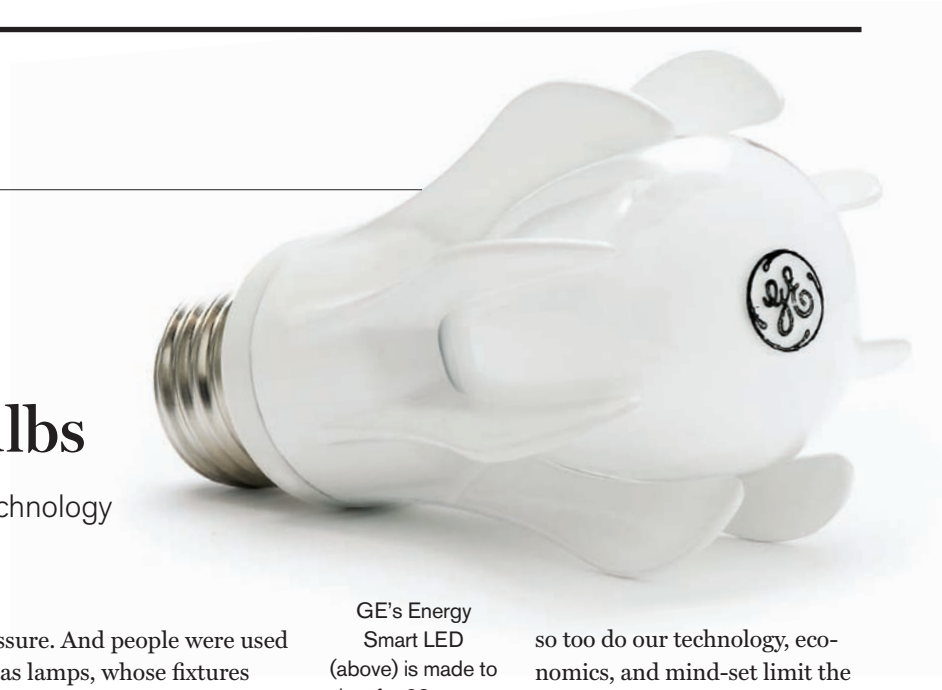
“I’m sure the iPhone 10 will have a DNA-sequencing module.”

Andreas Sundquist, CEO of DNANexus, a startup offering an online genomic analysis service.

RANT

The Problem of Path Dependence and LED Light Bulbs

Why are we cramming 21st-century technology into a socket designed by Edison?



GE’s Energy Smart LED (above) is made to last for 23 years.

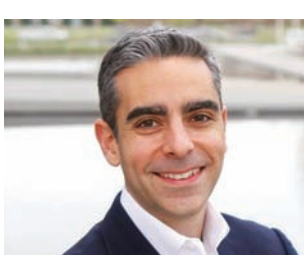
LED lights, mass-produced as tiny individual diodes, can be configured into any shape you can imagine. In the future, they could cover large surfaces, curved or flat, mimicking the light that comes through windows and skylights. They can be used to create diffuse or concentrated illumination, in a radiant or beam configuration. Yet for all their flexibility, the way they’re most likely to show up is as something that looks approximately like a light bulb and gets screwed into a traditional light socket.

That is ridiculous. Edison’s bulb had to be roughly spherical in order to contain a vacuum while withstanding atmospheric pressure. And people were used to gas lamps, whose fixtures could be repurposed for electric lights. Because of this, more than 100 years later, we have to cram LEDs into something that requires space-age fins to keep it from overheating?

In economics and social science, this phenomenon is known as “path dependence.” The simplistic definition of path dependence is that “history matters,” but there’s an even better way to think about it, and that’s as a sort of evolutionary constraint. Just as evolution is forced to build upon what came before, preserving and reusing parts (like genes) along the way, so too do our technology, economics, and mind-set limit the ways in which we can progress.

Our world is full of light sockets and electrical wiring that can’t be reconfigured without punching holes in the wall, which is why we’re stuck with LED light bulbs that exploit only a fraction of this technology’s potential. Path dependence seems simultaneously insane and unavoidable. Yet perhaps we can avoid it with new standards and new notions of how and where to place lights that are infinitely more flexible than the sort we’ve grown up with.

—CHRISTOPHER MIMS



THREE QUESTIONS FOR

DAVID MARCUS

The new head of PayPal is pushing the service into physical stores.

1 Many big retailers now let me use PayPal at the register. All I do is provide my cell-phone number and PIN. Will we soon stop carrying cash and credit cards?

Ultimately the consumers will decide how they want to pay. But the payment experience, to me, is going to move out of the way. My favorite [example] is location-based payments, where the merchant knows you’re in the store and the transaction happens with no friction, flawlessly, without you doing anything.

2 Why is that beneficial?

That becomes a tool for the merchant to treat you [better]. If you go to Peet’s coffee in San Francisco but now you want to go to Peet’s coffee in Palo Alto, you’re greeted by your name despite the fact that it’s your first time in that store. They know what your favorite drink is, and they’ll prepare it for you. We remove the friction from the payment experience—nobody likes to pay, everybody likes to shop—but we also enable you to have the best possible shopping experience.

3 How can PayPal maintain an advantage while other companies develop mobile payment systems?

Innovation at scale in payments is really hard. It’s really easy to get some initial buzz when you launch a product. [But] to this day, no one has succeeded in signing up consumers at a meaningful scale for a digital wallet service—no one except us. We need to continue innovating, [but] as long as we continue doing that, because we have the scale advantage, we’ll be fine. —RACHEL METZ

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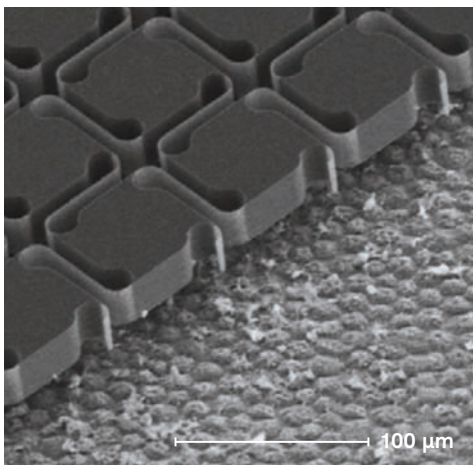


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6 The percentage of U.S. home solar-panel installations handled by SolarCity in 2010. The company deals with solar's high cost by leasing panels to customers.

13 SolarCity's percentage in 2011. That is more than double the share anyone else has, according to GTM Research.



This photovoltaic retinal prosthesis is a flexible sheet of silicon pixels that convert light into electrical signals, which can be picked up by neurons in the eye. A scanning-electron micrograph shows the implant in a pig's eye.

BIOMEDICINE

A Smarter Prosthetic for the Eye

A new type of implant requires less hardware than existing devices and could restore more vision.

Retinal implants powered by light could reverse some vision loss with simple surgery.

The new implant, which works like a combination digital imaging chip and photovoltaic array, requires much less bulky hardware than previous designs. The devices have yet to be tested in live animals or human patients, but the implants are exciting researchers because they might restore more vision than other retinal prosthetics being worked on.

People suffering from some forms of blindness, including macular degeneration (the most common cause of blindness among older people), have lost the light-sensing cells in the retina but still have the underlying nerve cells that convey visual information to the brain. Retinal implants use electrodes to stimulate those nerves. Typically, the prosthetics require bulky electronics that sit on the eye to supply power, image data, or both to a chip inside the retina. The more hardware that's installed in the body, the greater the risk to the patient. And the complexities of the electronics have typically limited the pixel counts of these systems, inhibiting image quality.

The new design, described in the journal *Nature Photonics*, gets around these problems by using light as a power source.

The device, designed by researchers at Stanford University, combines infrared video-projection goggles with a small, wire-free chip implanted inside the retina. A camera on the goggles transmits video to an image processor, which sends a signal back to infrared projection screens inside the goggles. The infrared image is picked up by a compact array of photovoltaic pixels implanted right where light-sensing cells would be in a healthy eye. Each pixel contains three infrared-sensitive diodes facing the inside of the eye. The diodes convert light into electricity that's pulsed out to the nerve cells by electrodes facing the back of the eye.

Other researchers have tried to develop photovoltaic retinal implants, but they failed because an implant couldn't get adequate power from "the light that you get into the back of the retina at the equator on a sunny day," says Stanford researcher James Loudin. That's why the Stanford system doesn't rely on light that comes into the eye, using the projection system to intensify it instead. Infrared light is used because that won't damage eye tissues and will not be picked up by any remaining light-sensitive cells in the eye, which would muddle image perception, Loudin says.

The Stanford scientists are experimenting with various designs, including a flexible silicon array that can bend to the curvature of the eye. The next step is a few years of safety testing before clinical trials. —KATHERINE BOURZAC

TO MARKET

Light-Powered iPad Keyboard

This combination iPad case and keyboard from Logitech uses a photovoltaic technology called dye-sensitized solar cells, which are highly efficient at producing electricity from indoor light. The photovoltaic cells recharge an onboard battery that provides power to the keyboard—which is part of the case that protects the iPad. These cells are made by G24 Innovations in Cardiff, Wales, based on technology originally invented in 1991 by Michael Grätzel at the Swiss Federal Institute of Technology in Lausanne, Switzerland.

Solar Keyboard Folio

COMPANY Logitech

PRICE $130

AVAILABILITY Now



NATURE PHOTONICS/STANFORD; COURTESY OF LOGITECH

Spain: Innovations and International Successes



SPAIN'S TECHNOLOGY SECTORS have made dramatic advances in recent decades. In personalized medicine and electronic health records, in desalination, in renewable energy, and in many other areas, Spanish companies have built experience at home that they have taken overseas with great success.

In the transportation sector, Spain has built a remarkable network of high-speed rail lines, which stretch around the country and link major economic centers. This achievement has made Spanish rail a real inspiration. Here in the United States, President Obama presented Spain's rail success as a model when he detailed the administration's goals for our own rail system.



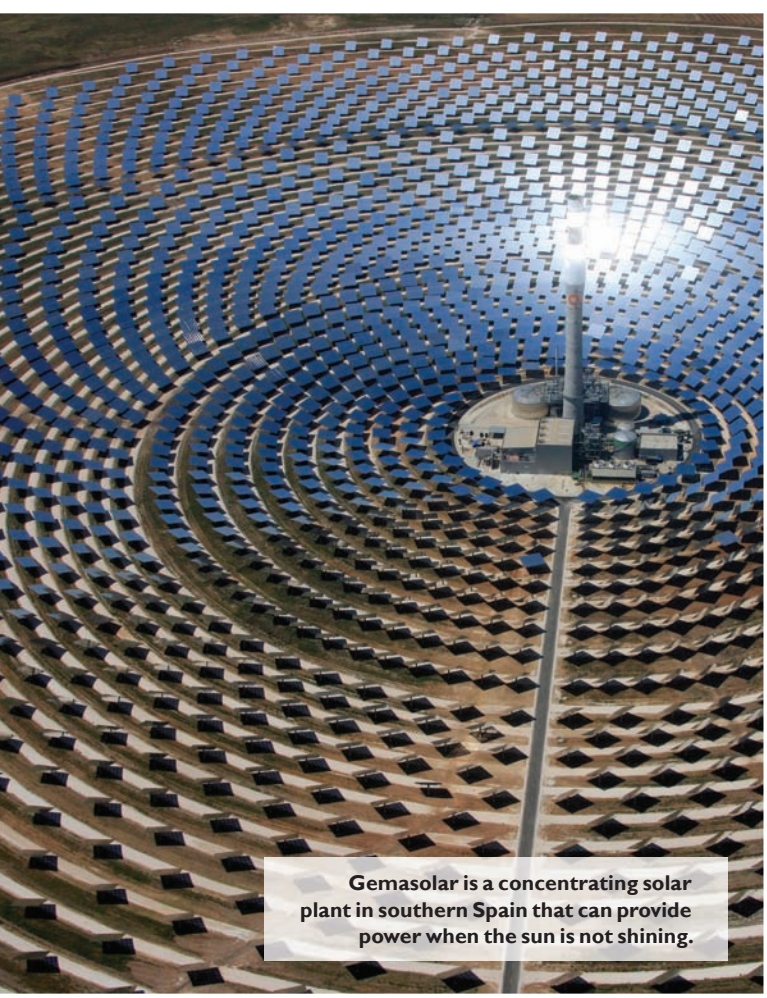
The Spanish health care system has consistently spent less as a percentage of GDP than other industrialized countries, while its citizens have enjoyed what the World Health Organization considers to be one of the very best health care systems. This has been achieved to no small degree because of the efforts and successes of Spanish companies.

The Spanish government, and Spanish companies, also bet heavily on renewable energy, and they are now enjoying the rewards. Not only does Spain boast a record percentage of electricity generated by renewable sources—wind, solar thermal power, and photovoltaic panels—but the companies that made it possible have since taken the lead in some of the most significant international renewable energy projects.

In the article that follows, you'll read about many accomplishments of Spanish companies, in sectors that span a wide range of technologies. Spain's advances have led to success for industries not just in Spain, but around the world.

Introduction by KATHLEEN D. KENNEDY

President, MIT Enterprise Forum; Chief Strategy Officer, Technology Review



Gemasolar is a concentrating solar plant in southern Spain that can provide power when the sun is not shining.

PRODUCING ENERGY, RENEWABLY

Last year, under the brilliant sun in the south of Spain, a concentrating solar power (CSP) plant called Gemasolar began operations. The 19.9 megawatt plant is the world's first commercial-scale tower CSP system to incorporate a storage system, allowing it to operate when the sun is not shining. (CSP is also known as "solar thermal," since it capitalizes on the sun's heat.)

The plant's 2,650 heliostats, each with120 square meters of mirrors, direct the sun's rays to the top of the 450-foot pillar, where molten salts are heated to a temperature above 500°C. That heat transforms water into steam, which turns turbines that generate electricity. Most important, the salts retain their daytime heat well into the evening hours. The plant can provide stored power for as long as 15 hours so the tower can meet peak evening demand, around 8:00 PM in winter and 10:00 PM in summer. Torresol, a joint venture of the Spanish engineering company Sener and Abu Dhabi's renewable energy company Masdar, designed and built the tower.

Gemasolar is the latest of Spain's many successes in renewable energy, both at home and overseas. Spain's government, concerned about the country's dependency on oil and its relatively tenuous connection to the greater European power grid, created favorable conditions for renewable energy in Spain, particularly solar (both photovoltaic panels and solar thermal) and wind power. Spain leads Europe in wind-generated electricity, and its installed capacity ranks among the highest in the world. Spain leads the world in installed solar thermal capacity, boasting more than double that of the second-place United States.

The U.S. provides a strong market for Spanish CSP companies. Abengoa is developing California's Mojave Solar, a solar thermal plant that will come online in 2014 and, with 280 megawatts of capacity, provide power for 54,000 homes. Mojave Solar will be the 16th Abengoa-developed solar thermal plant, and its second in the U.S. (Another is currently under construction in Arizona.) Another company, Acciona, has built a solar thermal plant in Nevada.

When it comes to solar thermal, says Luis Crespo, director of the Spanish solar thermal industry association Protermosolar, "most of the projects in the U.S. depend on Spanish technical assistance," even for installations not headed by Spanish companies.

Wind power continues to generate excitement as the relatively mature industry moves into new territories. Iberdrola, an international leader in wind farm operations, has completed the construction of one of the world's largest wind farms, with 304 megawatts of installed capacity, in Ohio. That farm also includes technology from wind-turbine powerhouse Gamesa, which supplied 152 turbines.

Both companies manufacture and operate technology for wind farms across the U.S., and in fact across most of the world. Iberdrola has installed more than 13,000 megawatts of capacity in 23 countries and is also moving into offshore wind. The Spanish

PHOTO: © TORRESOL ENERGY



Spain's high-speed rail network has garnered praise from around the world.

enterprise Acciona, which operates on four continents, is the leading wind power company in Mexico.

The recent growth of wind and solar in the U.S. has come about in part because of the Obama administration's interest in promoting the development of energy from multiple sources, including renewables. Speaking at a Spanish conference on "smart cities" in June, 2011, Joseph Hurd, the U.S. Department of Commerce's senior director for export promotion and trade policy, discussed the proposed American Power Act (which attempts to set standards for energy savings and the emissions of harmful gasses) and the American Recovery and Reinvestment Act of 2009 (which supports renewable energy). Hurd noted that Spain is the ninth-largest investor in renewable energy in the U.S., and second in terms of investment growth, employing 70,000 Americans.

Spanish companies design critical parts and systems to support these massive renewable energy installations. Gamesa, which continues to innovate in blade and turbine design, has provided the technology for more than 24,000 megawatts of wind power in 35 countries. And Siliken has been recognized internationally for the quality of its PV modules; it has developed proprietary systems to purify solar-grade silicon. The company recently opened a new manufacturing facility, Siliken's fourth factory, in Ontario. (Siliken also operates in Spain, Romania, and Mexico.) Siliken has also begun production of a significantly more efficient solar cell, which will lead to a reduction in both the size of a given installation and its cost.

FROM CITY TO CITY

The road between Madrid and Barcelona, Spain's two largest cities and the country's economic centers, stretches nearly 400 miles, roughly the same distance as from Los Angeles to San Francisco. By automobile, this trip takes about six hours. But by high-speed rail, which cruises smoothly at an average of 200 mph, the trip takes just over 2.5 hours.

The Madrid-Barcelona line opened in early 2008 and is one of the key achievements of the Spanish high-speed rail network, which has garnered praise from around the world. Spain's web of more than 1,800 miles of high-speed lines is centered on Madrid and also links cities along its coasts; the country is second only to China in high-speed track mileage. Spain was also the first country to equip its high-speed network with the most advanced signaling system, which will eventually become the European standard.

This domestic experience has given Spanish companies expertise in rail construction and management, train building, signaling, and the accompanying telecommunications and control systems that high-speed rail demands to compete on the international market.

"We have a model in Spain that has worked because citizens and politicians have supported railways," says Pedro Fortea, director of MAFEX, the Spanish railway association. "So people from other countries come to see what we've done—how we have cities with trams, metros, and integrated public transport systems, with

PHOTO: INDRA

high-speed connections with airports—and how institutions and private companies together have financed these projects. These are excellent references for Spanish companies."

Spanish companies have completed or are involved in rail projects in more than 90 countries on five continents, including Turkey, Brazil, the U.S., India, and Ireland, and countries across North Africa and Central Asia. One Spanish consortium—CAF is furnishing the trains, the OHL group is in charge of engineering and construction, and Dimetronic is supplying signals—won the bidding for construction of a high-speed line between Ankara and Istanbul. OHL also recently won a contract to extend the Miami-Dade County Metrorail to the nearby airport.

India presents major opportunities for Spanish rail companies: the Talgo train manufacturing company will soon be opening an office there, and CAF is already building a factory in New Delhi. The engineering company Ineco won the feasibility study contract for one of India's planned high-speed lines.

In the most significant news for the Spanish rail industry, a consortium of a dozen Spanish companies and public authorities was recently awarded a 12-year contract to construct, operate, and maintain a new high-speed line between Mecca and Medina in Saudi Arabia, in partnership with the Saudi Railway Organization.

This rail consortium is the largest one created to date by Spanish companies, and the project is the largest so far of its kind. Talgo, one of the country's two top train manufacturers, will supply the trains. OHL, Copasa, and Imathia will develop the infrastructure, and Dimetronic will supply the signaling. The information company Indra will manage telecommunications and control, and Cobra, Inabensa, and OHL will install the electrical infrastructure.

Three government-owned companies will also provide services to the Saudi project: Renfe, Spain's national service provider, will manage operations, and its infrastructure administrator, Adif, will provide the critical expertise for the management of stations and traffic control. Ineco, a government transportation consulting company, serves as the project's lead contractor.

"Even though we have a lot of experience developed in Spain, this is a huge opportunity to show our experience abroad," says José Solorza, Ineco's Asia and Africa area manager.

Manuel Benegas, director of operations at Ineco, estimates that the on-track tests should begin by the end of 2014. The Spanish Ministry of Development hopes to capitalize on this success to sell similar complete projects in the U.S., Russia, and Brazil, whose governments have stated their commitment to developing high-speed rail.

Advances in transportation management extend beyond railways, onto highways and city roads as well. Spanish companies are world leaders in the management of toll roads, expert at developing and integrating sensors and barrier-free tolls to enhance traffic flow and make ticketing easy. Other companies are pioneering parking guidance systems, which direct drivers to free spots in parking garages or along city streets.

PURIFYING WATER

In the 1960s, Spain's government saw a potential problem brewing. The rocky, sunlit Canary Islands, off the coast of northern Africa, were attracting tourists in increasing numbers. But while there was plenty of space to house those tourists, the supply of potable water could not increase to meet the demand. And so Spain turned a challenge into an opportunity. The government invested in developing brand-new technology that uses membranes to filter the salt out of salt water, and Spanish companies eventually developed the technologies to utilize those membranes in treatment plants. The result: Europe's first desalination plants.

Today, Spain produces more desalinated water than any other country in Europe, and is one of the world's top producers. Spain's more than 500 plants treat more than 200 billion gallons of water per year.

"In only a short period of time in Spain, we developed a great deal of infrastructure," says Angel Cajigas, director of ATTA, the Spanish business association for water treatment. "And this has given us a lot



The Alicante desalination plant is one of more than five hundred in Spain.

PHOTO: ACCIONA

of experience in design, construction, and operations. The technology has developed as well," making Spanish companies extremely competitive on the world market. In fact, Cajigas adds, of the top 20 companies in the world active in desalination, seven are Spanish.

In 2009, a new large-scale desalination facility was completed in the city of Barcelona. The Prat de Llobregat plant, which can supply up to 20 percent of the city's drinking water, won a 2010 Global Water Award for technical achievement from the industry magazine *Global Water Intelligence*.

The plant employs more than 5,200 solar panels and a wind turbine, along with energy efficiency technologies and energy recovery features. All together, these reduce the facility's environmental impact and its operating costs. (A significant percentage of the cost of running a desalination plant derives from its energy requirements.)

"Companies are always innovating," says Cajigas. He adds that companies are beginning to use filtration membranes to reutilize wastewater. Companies are designing more compact plants, and ones that are powered by renewable energy. Some companies are also developing new methods to disinfect water, increasing the ability to treat extremely low levels of contaminants. Information technology companies have developed systems to manage and integrate the massive information stream water treatment plants require—pressure and flow data, home meters to measure consumption, information about the available and consumed volumes of water, among other data—to enable smarter water management.



Innovations such as these have made Spain's desalination plants some of the best in the world, and have enabled Spanish companies to compete worldwide to design, construct, and operate water treatment and desalination plants. Some Spanish companies are involved in building and operating the plants, while others manufacture products to serve the water treatment market, such as valves, motors, pumps, and filtration systems.

Spanish water purification companies are active today in more than 30 countries, from Chile to Australia, in North Africa, the Middle East, India and China. They're developing more than 30 desalination plants, along with dozens of other water purification plants. Acciona Agua is part of the partnership behind one of the world's largest desalination plants, in Adelaide, Australia, and Valoriza Agua is constructing one in Perth. And discussions are underway for the first desalination plant in sub-Saharan Africa, in Namibia. Other companies, including Befesa, Aqualia, and Cadagua, are also well-positioned internationally.

The U.S. is also home to three desalination plants built or operated by Spanish companies: two in Florida and one outside Boston. In Tampa, the Tampa Bay Desalination Plant had been beset with problems since its construction began in 1999. After Acciona Agua took over the plant, in partnership with American Water, it finally began operations in 2008. Today the plant purifies 25 million gallons a day and supplies 10 percent of the drinking water for the region.

Water treatment extends, of course, beyond desalination, into conventional water purification for drinking water and beyond, and into industrial purification to deal with waste from industries like mining.

"Spanish companies are very competitive in water treatment," says Cajigas. "This is one of our fundamental strengths."

INDUSTRY TO SUPPORT INDUSTRY

Industries in sectors as varied as power generation, aerospace, automotive, rail, and domestic appliances depend on machine tools to create their products. And the Spanish companies that support their efforts—machine tool manufacturers as well as companies that produce accessories, component parts, and tools—provide the necessary means. In 2011, exports from Spain reached 120 countries and accounted for more than 80 percent of the country's overall business in this sector.

Spain's machine tool industry has been "supplying technology and production equipment to the main sectors of the economy for more than 65 years," says José Ignacio Torrecilla, president of Advanced Manufacturing Technologies, the Spanish trade association. This has helped Spanish companies "improve their competitiveness and that of the country," he adds.

Today, Spain's machine tool sector is the third largest in the European Union, and includes some of the world's leading companies. "To make things in steel—machinery, foundry, mills, stamping, lathes—these are traditional skills of people here," explains Félix Remírez, commercial manager of the machine tool company Fagor Arrasate, referring to the long metalworking tradition along the lush, green mountains in the north of Spain.

Machine tools can transform coils or sheets of metals into all the shapes and components needed for the trappings of modern life. They perform tasks such as rolling and stretching metal into flat sheets; stamping it into all manner of shapes; cutting, drilling, and grinding to precise specifications. And their precision has increased dramatically in recent years, as companies such as Nicolás Correa,

which makes milling machines, and Fagor Arrasate, which designs and builds machines such as stamps and presses, have taken advantage of the latest motors and computer controls to enable faster, more exacting manufacturing.

For the automotive sector, Fagor, which tailors all its machines to a company's needs, has completed a new line of completely automated and synchronized presses that operates nearly 50 percent faster than previous models. They recently installed one such press for Volkswagen in South Africa. They have also sent the latest development of a blanking line (which creates shapes in sheets of material), 50 percent faster than previous ones, to a company in South Carolina that manufactures parts for BMW.

In fact, many Spanish machine tool companies excel in the automotive sector, combining the national expertise at machining with a history of hosting manufacturing from automakers that include Ford, Volkswagen, Renault, Mercedes, and Nissan.

Last year Nicolás Correa provided milling solutions to British Aerospace, which manufactures parts for military aircraft. And Danobat, another major manufacturer, supplies milling and turning machines to companies that create parts for aerospace, wind turbines, and railways.

Though many of these companies manufacture their machines primarily in Spain, some also maintain overseas offices and plants. Danobat opened an office in China in 2011, and Fagor has a manufacturing facility there. Spanish automotive companies, including Cie Automotive, Gestamp, Trimplast, and Fagor, are expanding into the rapidly growing South American market, particularly in Brazil.



Spanish machine tool companies export to 120 countries.

Spanish machine tool companies have a tradition of pooling and coordinating their resources to benefit the industry as a whole, both in jointly-financed research centers and in national and international projects. Some of these projects have resulted in, to take a few examples, ultraprecise new milling machines; better "intelligent" features to enable higher-precision machines that can be operated more easily; and improved sustainability and energy-saving features of machines and parts, minimizing the environmental impact.

For the food production industry, Spanish companies export their solutions around the world. Spanish food has exploded in popularity over the past few decades, along with the popularity of Spain's agricultural products, and Spain's experience in irrigating, cultivating, cleaning, separating, processing, and packing its products has grown as well.

Innovations in technology led Metalquimia to develop machines that dramatically shorten times to cure and dry meat such as salami and chorizo. NC Hyberbaric has created machines that take advantage of high levels of water pressure to kill microorganisms, endowing food with a longer shelf life without extensive processing or salt and additives. Other food sector companies market faster seeding machines, packing machinery that incorporates radio-frequency ID tags, and artificial vision to sort and classify products and produce more efficiently.

HEALTHIER FOR LESS

The Spanish health care system enjoys two remarkable accomplishments. It is among the least expensive per person among industrialized nations, in terms of the percentage of GDP it spends on health care. At the same time, it is ranked by the World Health Organization as among the best in the world, based on a number of parameters including effectiveness and financial fairness. Spain has achieved this because of successful partnerships between government authorities and private companies, producing innovations in patient treatment and technology solutions for managing the health care system.

Spain gradually introduced electronic health records (EHRs) during the past decade. By 2010, more than 95 percent of primary health care providers in Spain had used them, and more than 250 million prescriptions were being submitted electronically to pharmacies. These statistics place Spain among the leading users of this technology. A number of Spanish companies, including El Corte Inglés, Everis, Indra, and Oesia, are international leaders in EHR technology.



New approaches in personalized medicine have the potential to improve care and trim costs.

The move to EHRs provides significant cost and time savings, facilitating coordination and use of resources and granting opportunities for improved treatment. Everis, whose health care solutions cover more than 20 million users, is now building software to improve chronic disease management. The new product helps determine the level of care required for a variety of chronic diseases and the types of technologies that can meet a patient's needs at home. Everis began implementing its solutions in Spain in 2011; business director Santiago Martín says that so far the range of savings for chronic patients is 20 to 40 percent over traditional care.

The vast amount of information that electronic records can amass and process will help advance the field of "personalized" medicine, where diagnoses or therapies for illnesses such as cancer will be individually tailored, assisted by data on a patient's genetic profile and other relevant information. This has the potential both to improve patient treatment and trim health care costs, avoiding trials of expensive medicines that won't work. The Indra information company has initiated a "FutureClinic" project to research new algorithms and genomic information processing systems to meet such needs.

In order to provide a personalized approach to cancer, many companies are developing approaches that tailor appropriate medications to a patient's individual genetic makeup. One, Vivia Biotech, created a platform that evaluates the most popular combinations of drugs to treat blood cancers (leukemias, lymphomas, and myelomas). The technology can analyze thousands of blood samples and medication combinations in 48 hours, then rank the samples by how many tumor cells the protocol has killed.

Internationalization is a fundamental principle of all Spanish biotechnology and health care companies. Vivia Biotech has signed drug-development partnership agreements with U.S.-based pharmaceutical companies, and plans to enter the American market after it launches its personalized medicine test in Europe this year.

Progenika, which is also well positioned in the U.S., has developed a DNA chip that analyzes blood for a number of blood type variants in addition to the typical A/B/O and Rh positive or negative types. The chip has already been adopted to test for rare antigens in blood banks throughout Europe: identifying these variants can help avoid reactions that a chronic patient might suffer from repeatedly receiving blood that doesn't match perfectly. From its satellite office near Boston, the company has received U.S. approval for its tests, and has signed distribution agreements with multinationals that include Pfizer and Novartis.

AB-Biotics has also created a DNA chip, one that analyzes the patient's saliva for genetic variations that indicate responses to various drugs for psychiatric and neurological diseases. The company has already patented a number of its products in the U.S.

Spain's National Cancer Research Center (CNIO) partnered with Stanford University and the Life Length company (a CNIO spinoff) in a study published in *Cell* in 2012 that focuses on what the human genome may eventually tell us about diseases. The Spanish team helped to analyze the personal molecular and health data of Michael Snyder, director of Stanford University's Center for Genomics and Personalized Medicine.

Says CNIO Director Maria Blasco, "This study shows that diseases are a product of an individual's genetic profile as well as interaction with the environment. So far we know little about this correlation, while the use of human genome information to prevent and treat disease is still clearly in its infancy. But what we can see—the tip of the iceberg—is fascinating."

THE INFORMATION AGE

Information and communications technology, or ICT, now underlies nearly all the world's major commercial sectors. Spain has risen to the top in a number of these sectors, as Spain's information companies have provided international solutions for needs such as air and road traffic control, security in public spaces and digital ones, and mobile telecommunications. Spain was also the first country to employ a single broadcasting network for digital television. As a result, Spanish companies became experts in both low- and high-power transmitters and are active around the world in digital processing and transmission.

"The ICT sector in Spain boasts a large group of solid and competitive companies that are favorably positioned internationally, and are leading in their activity areas," says Jesús Banegas, president

PHOTO: PROGENIKA

of AMETIC, Spain's association of information technology and communications companies.

A number of key factors in Spain have encouraged the flourishing of the ICT sector. Since autumn 2008, all national identity cards have been issued in an electronic format. Spain was one of the first countries in the EU to adopt this technology and, with more than 25 million e-ID cards issued, Spain is an international leader in electronic signatures. Spain has also experienced rapid growth in the use of electronic health records.

Both have led to advances in information processing, and in security systems that safeguard a user's digital data and all transactions the citizen makes electronically. Companies have developed solutions to verify personal identification and allow safe and secure card use both in person and online.

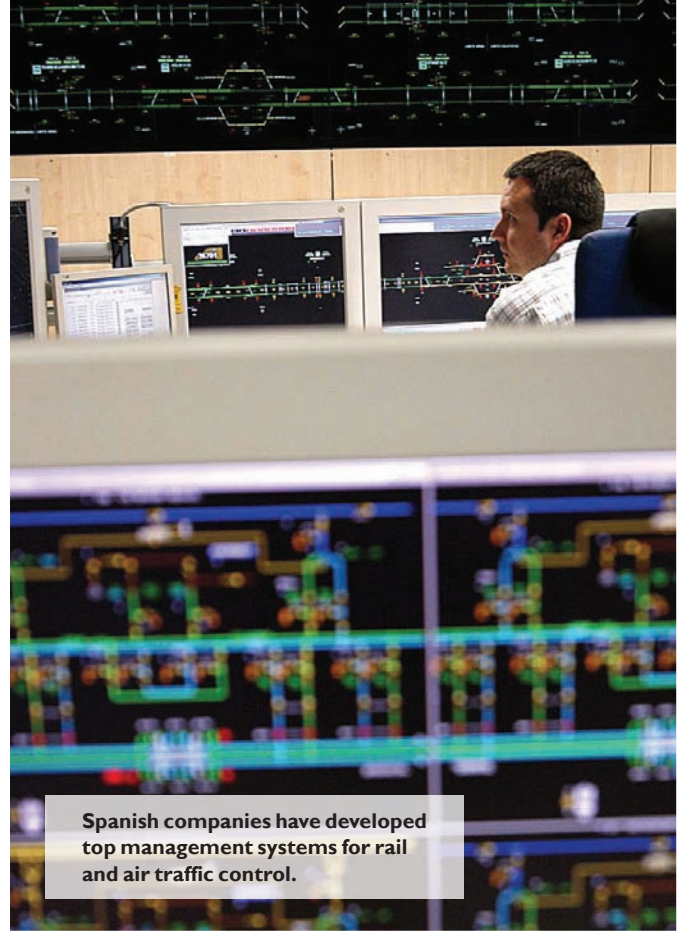
The implementation of the electronic ID has prompted the development of additional technologies. Informática el Corte Inglés, working with Investrónica, created the first digital TV decoder that is compatible with the electronic ID card. The device contains an ID reader and even allows users to access services via the television, if they have no computer or are unfamiliar with computer use.

Tourism, according to Juan José González, Indra's director of development strategy, temporarily doubles Spain's population every year. The country has built a modern network of internal flights and high-speed rail to accommodate their travel—and its companies developed sophisticated technology to manage air traffic and rail traffic. Indra's air traffic control system, implemented around the world, helps three out of every five flights in the world land safely.

The high demands of tourism and travel have also led to new technologies to securely identify travelers. One such solution, which the Ministry of the Interior has installed, is called the Automatic Border Control System, or ABC System. The first of its kind in Europe, the system pairs facial recognition with the signals from electronic passports or electronic IDs, and links the information to four large databases: passport inspection, electronic ID authorization, police data, and border control. And for the financial security of tourists and residents, in Spain and internationally, the company GMV developed a system to ensure monitoring of all ATM operations, and prevention of any unauthorized access.

Transportation and security systems come together in intelligent traffic systems, which can manage and operate sections of road, and also communicate data related to public transportation to riders. Spanish companies are implementing intelligent traffic control in a number of cities in China, and are also operating toll roads in North America.

The smart electrical grid provides another opportunity for ICT companies to manage huge amounts of data from electric companies together with usage information from consumers, in order to conserve energy and save money. South and Central America may be important new markets for this technology, as their emerging economies are deploying the new technologies from the bottom up rather than substituting for old ones.



Spanish companies have developed top management systems for rail and air traffic control.

PHOTO: INDRA

The migration of digital services to the cloud has influenced the activities of Spain's two largest ICT companies, Indra and Telefónica (which is the world's fifth largest telecom company). Both Indra and Telefónica, along with other major ICT companies, are moving into digital services and cloud computing, and are integrating data from different services in order to create the smarter cities of tomorrow. Their solutions might involve integrating traffic control, police notifications, and hospitals and paramedics in order to deal quickly with any emergency.

Spanish digital skills extend to excellence in visualization as well: its companies created graphics for the televised vote tally in the U.S. 2008 presidential elections and the NASDAQ displays in Times Square. A Spanish company designed a program to create the realistic water images used in computer graphics in Hollywood. Yet another is playing a key role in the postproduction stereo 3-D processing for Peter Jackson's two upcoming film adaptations of *The Hobbit*.

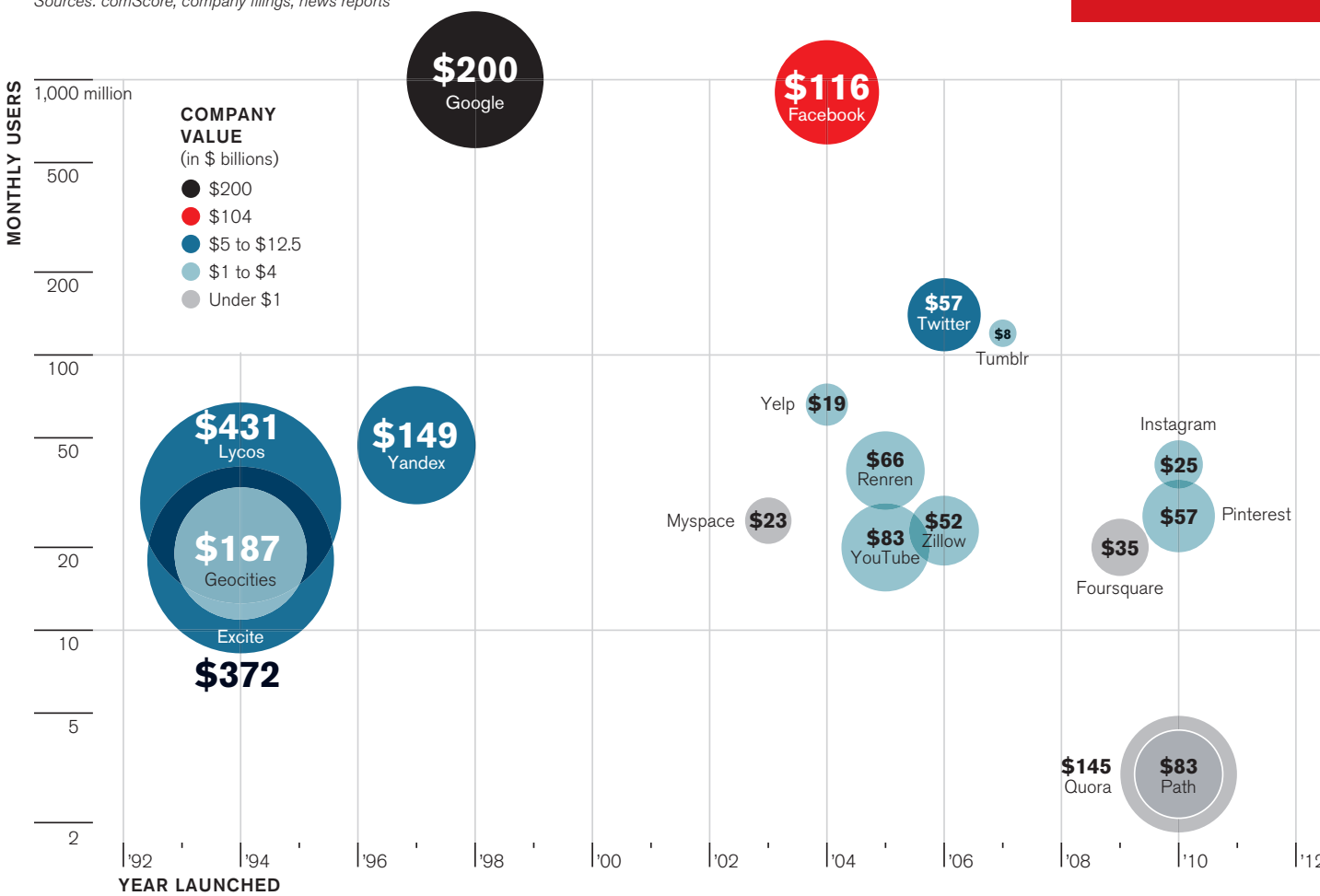
Connectivity remains crucial across all sectors, says AMETIC's Banegas, pointing out that Spain heads European countries in smartphone ownership and use of 3G networks, and Spanish companies lead in providing Internet and broadband access. He says the sector will surge ahead "anywhere connectivity and mobility are a key factor."

Learn more at www.technologyreview.com/spain
or visit www.spaintechnology.com

Market Value per User

Circle size reflects value per user—which is implied by a company's market capitalization, its valuation in private investment rounds, or its highest acquisition price.

Sources: comScore, company filings, news reports



How Much Is a User Worth?

Estimates of the historical value of a Web audience put Facebook's IPO hype in perspective.

When Facebook went public in May, the company was valued at $104 billion, an astonishing figure for an Internet company. Was the figure preposterously high? That depends on how you look at it. Facebook's value lies in its enormous audience—901 million people every month who are potential viewers of advertisements and buyers of virtual goods. So you could think of Facebook this way: it was worth about $116 for every user it had. On that basis, the company's valuation wasn't as high as Google's ($200 per user) or even the question-and-answer service Quora's ($145). This metric also reveals that investors appear much less optimistic that Twitter (worth less than $60 per user) or Tumblr (about $8) will profit handsomely from their very large audiences.

Another reason this metric is useful: it indicates that for all the hype around Facebook and its kin, the situation isn't as hyperbolic as it was in the dot-com boom. Remember Excite, one of the first Web portals? It and its 18 million users were worth as much as $6.7 billion—$372 per user—to the @Home Network in 1999. The next year, Lycos was valued at as much as $12.5 billion, or $431 per user. It might be of little solace that valuations aren't as inflated as they were a dozen years ago, but at least now, unlike then, there is a sizable amount of Internet ad revenue to vie for.

—Brian Bergstein and Mike Orcutt

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q&a

Max Levchin

The PayPal cofounder wants to see more startups trying for bigger things.

Technology startups, especially those in Silicon Valley, love to talk about innovation. But how good are they at actually inventing and commercializing important technologies? Not as good as they should be, says Max Levchin, a computer scientist who cofounded PayPal (earning him *TR*'s "Innovator of the Year" award in 2002) and is now an angel investor. Levchin, along with fellow PayPal founder Peter Thiel and former chess champion Garry Kasparov, is completing a book called *The Blueprint*, which will outline how and why startups should tackle much harder problems. Levchin, 36, says too many of the country's best programmers are working for companies that have little prospect of doing anything transformative.

Levchin's own startup record is mixed. Although building PayPal's online payments technology into a trustworthy system was a technically difficult and risky project that ultimately prospered, he later founded Slide.com, which was best known for creating a somewhat silly series of Facebook applications such as Superpoke! Pets. Google bought Slide in 2010 for about $200 million but shut down most of its services last year.

Levchin discussed his ideas with *Technology Review* reporter Conor Myhrvold.

_TR:_ What concerns you the most about the startup culture today?

Levchin: I feel like we should be aiming higher. The founders of a number of startups I encounter have no real intent of getting anywhere huge. They just want to build a company that is likely to get acquired for a meaningful, but not necessarily enormous, amount of money. The acquisition price doesn't really matter, but it serves relatively well to measure the consequence of the startup and therefore indirectly measures the ambition of the founders at the outset.

What's wrong with building a company in hopes it will be acquired?

I think it is less likely to result in truly revolutionary or groundbreaking companies being created. In Silicon Valley, the number of startups that could be easily confused with a feature [of some other service] is increasing relatively rapidly.

But what about big innovations in recent years like the rise of smart phones and social media?

There's a fair amount of disruptive technology going on. In general, the train of innovation is rolling along. I'm not too worried about innovation at large. The point I was trying to make is that there's an awful lot of effort being expended that is just never going to result in meaningful, truly disruptive innovation. And I think that's a problem. A lot of resources are getting soaked up by these lesser companies—most importantly, talented engineers, talented builders of things.

Why is this happening?

Typically these things go through the sieve of scarce resources—e.g., capital. When you try to raise money and your pitch sounds like "I'm going to look at that video game, clone it, and make it a little bit cheaper," under the right circumstances—under most circumstances—the potential backer says, "That's a terrible idea. I'm not giving a penny to this. Why don't you go invent something interesting?"

But the overabundance of capital that resulted from just enormous successes in Silicon Valley over the last few years has actually made it possible for such things to get funding, and they do. And so people are building things that are, at times, trivial.

In many respects, Slide seems as trivial as these other companies you think should be aiming higher. Do you wish you hadn't spent those years creating virtual pets?

Games and entertainment can aim pretty high. The world can occasionally be changed by an amazing piece of art or music or writing. At Slide we did some great work, but the result did fall short of my ambitions. I think the lesson learned for me was that I'm not that good at changing the world through art, and should stick to what I know: science.

Have you shaped your investments accordingly? Tell us about a startup you've backed that has a truly big idea.

I'm really excited about Kaggle. It's essentially a platform [that can tap the minds of the world's top data analysts]. People are frequently employed in places where they make great impact on their employer's data sets but are unavailable to make great impact on other data sets, so creating a platform where these people can be literally rented out per problem is really fabulous. Because then you have people that can still keep their jobs at NASA and solve radio telescopy data set problems, and on occasion dig into things like human genome projects and cancer research. I think that's a very powerful concept. tr

TIM WAGNER/ZUMA PRESS/CORBIS



“A LOT OF RESOURCES ARE GETTING SOAKED UP BY LESSER COMPANIES—MOST IMPORTANTLY, TALENTED ENGINEERS.”

Star Gazers

By TIMOTHY MAHER

Photographs by NOAH FRIEDMAN-RUDOVSKY

PHOTO ESSAY

The Atacama Desert in Chile is on the wrong side of the Andes. The trade winds that might bring moisture from the east get caught in the mountains instead, making this the driest place on Earth. But this turns out to be perfect for the Atacama Large Millimeter Array—the most powerful telescope in history. At 5,000 meters—about as high as Everest Base Camp—light pollution is minimal, and the heavens seem near.





The Chajnantor Plateau of the Atacama dwarfs the radio telescopes of ALMA, a project that began construction nine years ago and is still in progress. ALMA, a collaboration among scientists and governments from Europe, Asia, and North and South America, aims to gather a fuller view of the universe than has ever before been possible.















At left, scientists and engineers work in the control room at ALMA. Radio frequencies received by the antennas are translated into data and carried by fiber-optic cables to the operations support facility, at top right.

Because the site's altitude is so inhospitable, the project's roughly 600 workers—scientists, technicians, office staff, and construction workers—sleep in the living quarters (top left) at a more tolerable 3,000 meters. Only a few guards and those working overnight stay at 5,000 meters.

Between 12-hour shifts, workers get some rest (above left) or dine with colleagues from the United States, Canada, Japan, Taiwan, Europe, and Chile (above right).

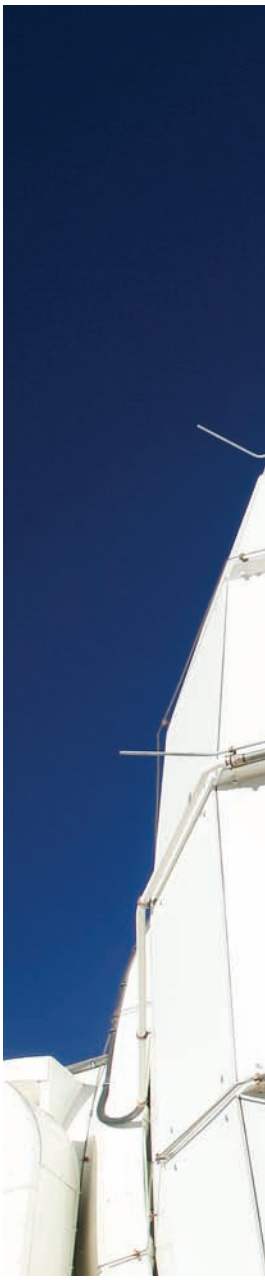
Top left, workers stand inside the "receiver room" of one of the radio telescopes that make up the project.

Top right, massive warehouses provide shelter for both the equipment and the workers, such as the technicians assembling an antenna at bottom.

At right, workers test a radio telescope being readied for operation. At bottom right, a scientist performs some final tests in the receiver room before taking this antenna online.





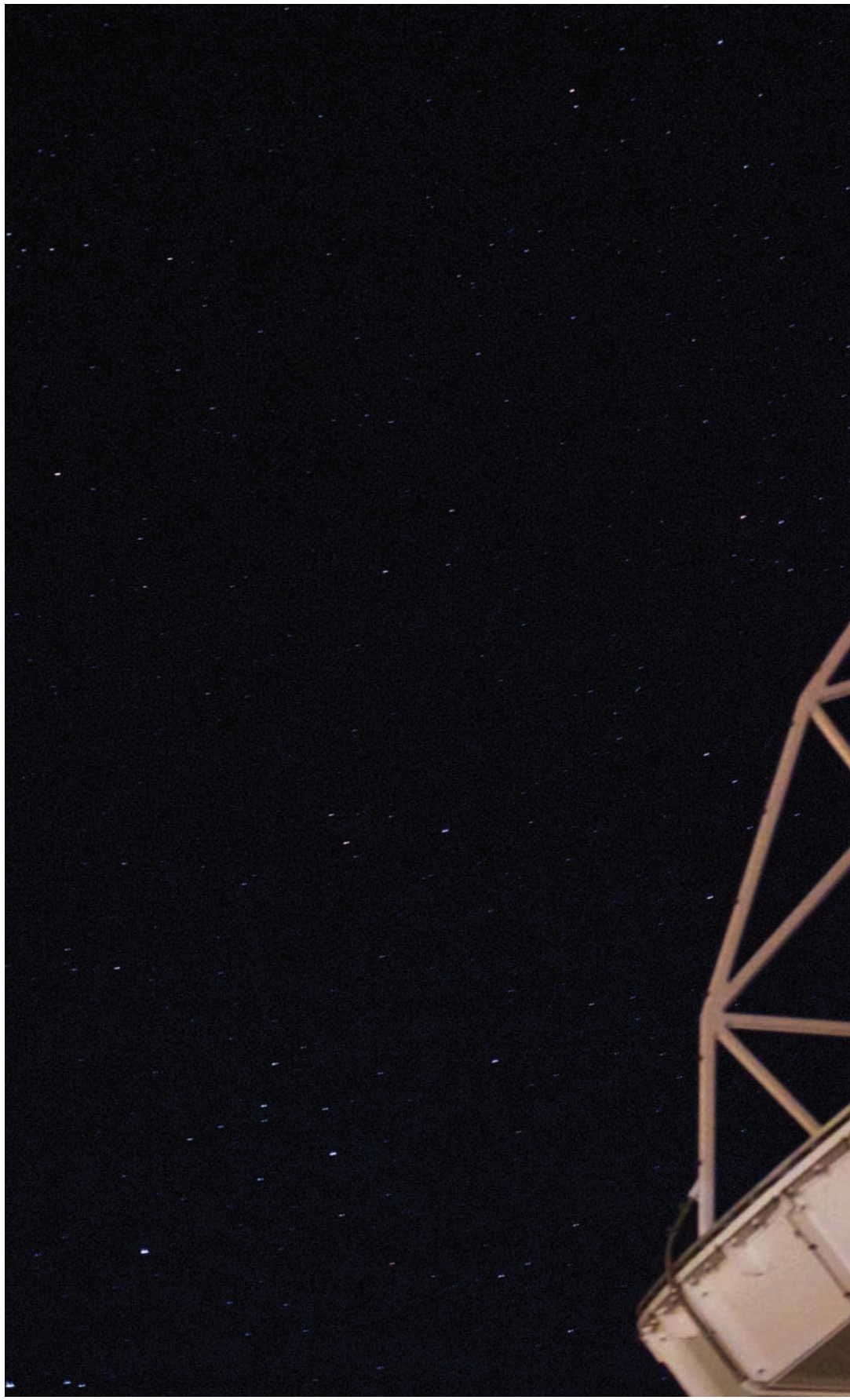







JLG





A radio telescope stands in the thin air of Chile's Atacama Desert, ready to receive data from the stars.



WHAT  KNOWS

Deep inside the company, a team of social scientists is hunting for unprecedented insights about human behavior. Their findings could lead Facebook to new ways of cashing in on our data—and they could reshape our understanding of how society works.

BY TOM SIMONITE
PHOTOGRAPHS BY LEAH FASTEN



Cameron Marlow calls himself Facebook's "in-house sociologist." He and his team can analyze essentially all the information the site gathers.

IF

FACEBOOK WERE A COUNTRY, a conceit that founder Mark Zuckerberg has entertained in public, its 900 million members would make it the third largest in the world. It would far outstrip any regime past or present in how intimately it records the lives of its citizens. Private conversations, family photos, and records of road trips, births, marriages, and deaths all stream into the company's servers and lodge there. Facebook has collected the most extensive data set ever assembled on human social behavior. Some of your personal information is probably part of it.

And yet, even as Facebook has embedded itself into modern life, it hasn't actually done that much with what it knows about us. Now that the company has gone public, the pressure to develop new sources of profit *(see "The Facebook Fallacy," p. 70)* is likely to force it to do more with its hoard of information. That stash of data looms like an oversize shadow over what today is a modest online advertising business, worrying privacy-conscious Web users and rivals such as Google. Everyone has a feeling that this unprecedented resource will yield something big, but nobody knows quite what.

Heading Facebook's effort to figure out what can be learned from all our data is Cameron Marlow, a tall 35-year-old who until recently sat a few feet away from Zuckerberg. The group Marlow runs has escaped the public attention that dogs Facebook's founders and the more headline-grabbing features of its business. Known internally as the Data Science Team, it is a kind of Bell Labs for the social-networking age. The group has 12 researchers—but is expected to double in size this year. They apply math, programming skills, and social science to mine our data for insights that they hope will advance Facebook's business and social science at large. Whereas other analysts at the company focus on information related to specific online activities, Marlow's team can swim in practically the entire ocean of personal data that Facebook maintains. Of all the people at Facebook, perhaps even including the company's leaders, these researchers have the best chance of discovering what can really be learned when so much personal information is compiled in one place.

Facebook has all this information because it has found ingenious ways to collect data as people socialize. Users fill out profiles with their age, gender, and e-mail address; some people also give additional details, such as their relationship status and mobile-phone number. A redesign last fall introduced profile pages in the form of time lines that invite people to add historical information such as places they have lived and worked. Messages and photos shared on the site are often tagged with a precise location, and in the last two years Facebook has begun to track activity elsewhere on the Internet, using an addictive invention called the "Like" button. It appears on apps and websites outside Facebook and allows people to indicate with a click that they are interested in a brand, product, or piece of digital content. Since last fall, Facebook has also been able to collect data on users' online lives beyond its borders automatically: in certain apps or websites, when users listen to a song or read a news article, the information is passed along to Facebook, even if no one clicks "Like." Within the feature's first five months, Facebook catalogued more than five billion instances of people listening to songs online. Combine that kind of information with a map of the social connections Facebook's users make on the site, and you have an incredibly rich record of their lives and interactions.

"This is the first time the world has seen this scale and quality of data about human communication," Marlow says with a characteristically serious gaze before breaking into a smile at the thought of what he can do with the data. For one thing, Marlow is confident that exploring this resource will revolutionize the scientific understanding of why people behave as they do. His team can also help Facebook influence our social behavior for its own benefit and that of its advertisers. This work may even help Facebook invent entirely new ways to make money.

Contagious Information

Marlow eschews the collegiate programmer style of Zuckerberg and many others at Facebook, wearing a dress shirt with his jeans rather than a hoodie or T-shirt. Meeting me shortly before the company's initial public offering in May, in a conference room adorned with a six-foot caricature of his boss's dog spray-painted on its glass wall, he comes across more like a young professor than a student. He might have become one had he not realized early in his career that Web companies would yield the juiciest data about human interactions.

In 2001, undertaking a PhD at MIT's Media Lab, Marlow created a site called Blogdex that automatically listed the most "contagious" information spreading on weblogs. Although it was just a research project, it soon became so popular that Marlow's servers crashed. Launched just as blogs were exploding into the popular consciousness and becoming so numerous that Web users felt overwhelmed with information, it prefigured later aggregator sites such as Digg and Reddit. But Marlow didn't build it just to help Web users track what was popular online. Blogdex was intended

Even as Facebook has embedded itself into modern life, it hasn't done that much with what it knows about us. Its stash of data looms like an oversize shadow. Everyone has a feeling that this resource will yield something big, but nobody knows quite what.



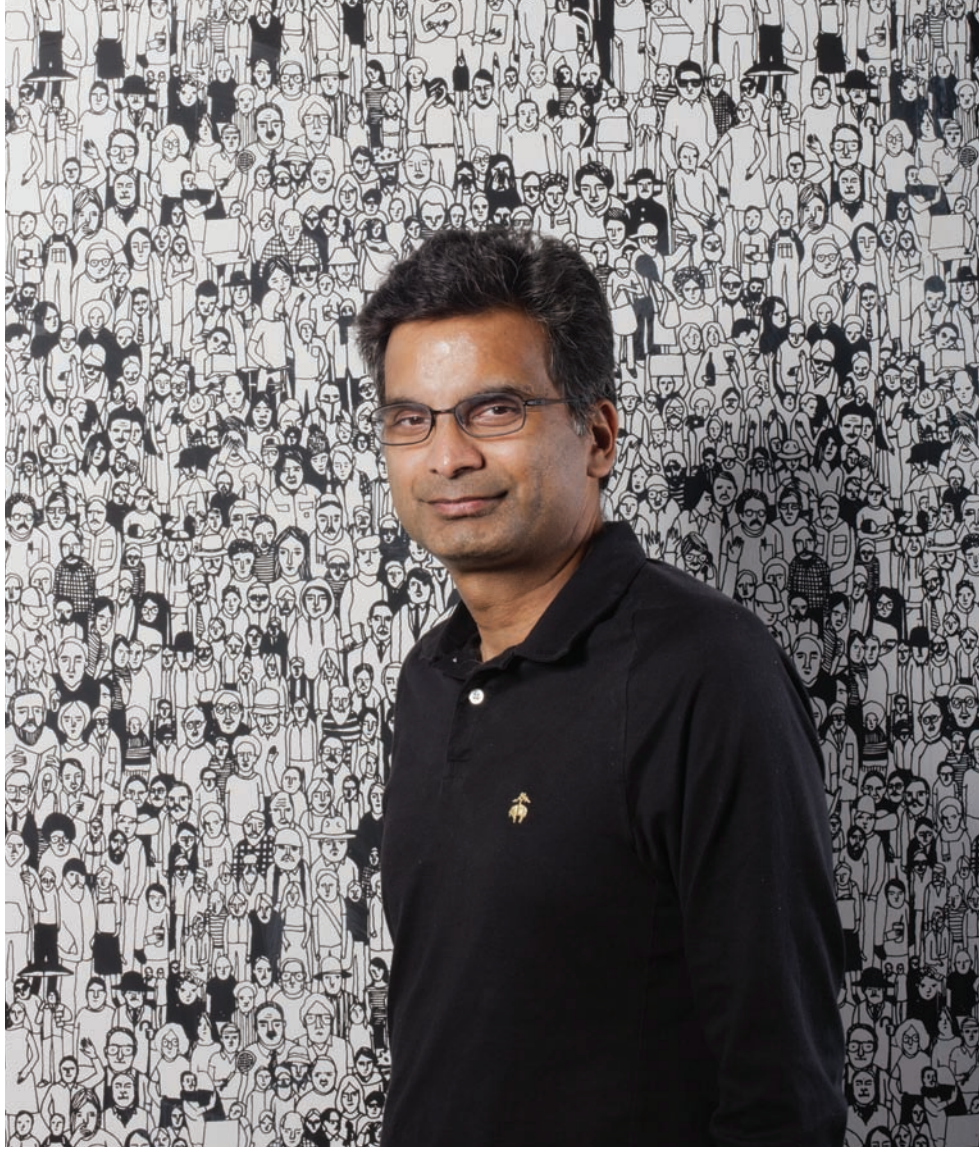
Eytan Bakshy experimented with the way Facebook users shared links so that his group could study whether the site functions like an echo chamber.

as a scientific instrument to uncover the social networks forming online and study how they spread ideas. Marlow went on to Yahoo's research labs to study online socializing for two years. In 2007 he joined Facebook, which he considers the world's most powerful instrument for studying human society. "For the first time," Marlow says, "we have a microscope that not only lets us examine social behavior at a very fine level that we've never been able to see before but allows us to run experiments that millions of users are exposed to."

Marlow's team works with managers across Facebook to find patterns that they might make use of. For instance, they study how a new feature spreads among the social network's users. They have helped Facebook identify users you may know but haven't "friended," and recognize those you may want to designate mere "acquaintances" in order to make their updates less prominent. Yet the group is an odd fit inside a company where software engineers are rock stars who live by the mantra "Move fast and break things." Lunch with the data team has the feel of a grad-student gathering at a top school; the typical member of the group joined fresh from a PhD or junior academic position and prefers to talk about advancing social science than about Facebook as a product or company. Several members of the team have training in sociology or social psychology, while others began in computer science and started using it to study human behavior. They are free to use some of their time, and Facebook's data, to probe the basic patterns and motivations of human behavior and to publish the results in academic journals—much as Bell Labs researchers advanced both AT&T's technologies and the study of fundamental physics.

It may seem strange that an eight-year-old company without a proven business model bothers to support a team with such an academic bent, but Marlow says it makes sense. "The biggest challenges Facebook has to solve are the same challenges that social science has," he says. Those challenges include understanding why some ideas or fashions spread from a few individuals to become universal and others don't, or to what extent a person's future actions are a product of past communication with friends. Publishing results and collaborating with university researchers will lead to findings that help Facebook improve its products, he adds.

For one example of how Facebook can serve as a proxy for examining society at large, consider a recent study of the notion that any person on the globe is just six degrees of separation from any other. The best-known real-world study, in 1967, involved a few hundred people trying to send postcards to a particular Boston stockholder. Facebook's version, conducted in collaboration with researchers from the University of Milan, involved the entire social network as of May 2011, which amounted to more than 10 percent of the world's population. Analyzing the 69 billion friend connections among those 721 million people showed that the world is smaller than we thought: four intermediary friends are usually enough to introduce anyone to a random stranger. "When considering another person in the world, a friend of your friend knows a friend of their friend, on average," the technical paper pithily concluded. That result may not extend to everyone on the planet, but there's good reason to believe that it and other findings from the Data Science Team are true to life outside Facebook. Last year the Pew Research Center's Internet & American Life Project found that 93 percent of Facebook friends



Sameet Agarwal figures out ways for Facebook to manage its enormous trove of data—giving the company a unique and valuable level of expertise.

had met in person. One of Marlow's researchers has developed a way to calculate a country's "gross national happiness" from its Facebook activity by logging the occurrence of words and phrases that signal positive or negative emotion. Gross national happiness fluctuates in a way that suggests the measure is accurate: it jumps during holidays and dips when popular public figures die. After a major earthquake in Chile in February 2010, the country's score plummeted and took many months to return to normal. That event seemed to make the country as a whole more sympathetic when Japan suffered its own big earthquake and subsequent tsunami in March 2011; while Chile's gross national happiness dipped, the figure didn't waver in any other countries tracked (Japan wasn't among them). Adam Kramer, who created the index, says he intended it to show that Facebook's data could provide cheap and accurate ways to track social trends—methods that could be useful to economists and other researchers.

Other work published by the group has more obvious utility for Facebook's basic strategy, which involves encouraging us to make the site central to our lives and then using what it learns to sell ads. An early study looked at what types of updates from friends encourage newcomers to the network to add their own contributions. Right before Valentine's Day this year a blog post from the Data Science Team listed the songs most popular with people who had recently signaled on Facebook that they had entered or left a relationship. It was a hint of the type of correlation that could help Facebook make useful predictions about users' behavior—knowledge that could help it make better guesses about which ads you might be more or less open to at any given time. Perhaps people who have just left a relationship might be interested in an album of ballads, or perhaps no company should associate its brand with the flood of emotion attending the death of a friend. The most valuable online ads today are those displayed alongside certain Web searches, because the searchers are expressing precisely what they want. This is one reason why Google's revenue is 10 times Facebook's. But Facebook might eventually be able to guess what people want or don't want even before they realize it.

Recently the Data Science Team has begun to use its unique position to experiment with the way Facebook works, tweaking the site—the way scientists might prod an ant's nest—to see how users react. Eytan Bakshy, who joined Facebook last year after collaborating with Marlow as a PhD student at the University of Michigan, wanted to test whether our Facebook friends create an "echo chamber" that amplifies news and opinions we have already heard about. So he messed with how Facebook operated for a quarter of a billion users. Over a seven-week period, the 76 million links that those users shared with each other were logged. Then, on 219 million randomly chosen occasions, Facebook prevented someone from seeing a link shared by a friend. Hiding links this way created a control group so that Bakshy could assess how often people end up promoting the same links because they have similar information sources and interests.

He found that our close friends strongly sway which information we share, but overall their impact is dwarfed by the collective influence of numerous more distant contacts—what sociologists call "weak ties." It is our diverse collection of weak ties that most powerfully determines what information we're exposed to.

That study provides strong evidence against an idea nagging many people: that social networking creates harmful "filter

bubbles," to use activist Eli Pariser's term for the effects of tuning the information we receive to match our expectations. But the study also reveals the power Facebook has. "If [Facebook's] News Feed is the thing that everyone sees and it controls how information is disseminated, it's controlling how information is revealed to society, and it's something we need to pay very close attention to," Marlow says. He points out that his team helps Facebook understand what it is doing to society and publishes its findings to fulfill a public duty to transparency. Another recent study, which investigated which types of Facebook activity cause people to feel a greater sense of support from their friends, falls into the same category.

But Marlow speaks as an employee of a company that will prosper largely by catering to advertisers who want to control the flow of information between its users. And indeed, Bakshy is working with managers outside the Data Science Team to extract advertising-related findings from the results of experiments on social influence. "Advertisers and brands are a part of this network as well, so giving them some insight into how people are sharing the content they are producing is a very core part of the business model," says Marlow. Facebook told prospective investors before its IPO that people are 50 percent more likely to remember ads on the site if they're visibly endorsed by a friend. Figuring out how influence works could make ads even more memorable or help Facebook find ways to induce more people to share or click on its ads.

Social Engineering

Marlow says his team wants to divine the rules of online social life to understand what's going on inside Facebook, not to develop ways to manipulate it. "Our goal is not to change the pattern of communication in society," he says. "Our goal is to understand it so we can adapt our platform to give people the experience that they want." But some of his team's work and the attitudes of Facebook's leaders show that the company is not above using its platform to tweak users' behavior. Unlike academic social scientists, Facebook's employees have a short path from an idea to an experiment on hundreds of millions of people.

In April, influenced in part by conversations over dinner with his med-student girlfriend (now his wife), Zuckerberg decided that he should use social influence within Facebook to increase organ donor registrations. Users were given an opportunity to click a box on their Timeline pages to signal that they were registered donors, which triggered a notification to their friends. The new feature started a cascade of social pressure, and organ donor enrollment increased by a factor of 23 across 44 states.

Marlow's team is in the process of publishing results from the last U.S. midterm election that show another striking example of Facebook's potential to direct its users' influence on one another. Since 2008, the company has offered a way for users to signal that they have voted; Facebook promotes that to their friends with a note to say that they should be sure to vote, too. Marlow says that in the 2010 election his group matched voter registration logs with the data to see which of the Facebook users who got nudges actually went to the polls. (He stresses that the researchers worked with cryptographically "anonymized" data and could not match specific users with their voting records.)

This is just the beginning. By learning more about how small changes on Facebook can alter users' behavior outside the site, the company eventually "could allow others to make use of Facebook in the same way," says Marlow. If the American Heart Association wanted to encourage healthy eating, for example, it might be able to refer to a playbook of Facebook social engineering. "We want to be a platform that others can use to initiate change," he says.

Advertisers, too, would be eager to know in greater detail what could make a campaign on Facebook affect people's actions in the outside world, even though they realize there are limits to how firmly human beings can be steered. "It's not clear to me that social science will ever be an engineering science in a way that building bridges is," says Duncan Watts, who works on computational social science at Microsoft's recently opened New York research lab and previously worked alongside Marlow at Yahoo's labs. "Nevertheless, if you have enough data, you can make predictions that are better than simply random guessing, and that's really lucrative."

Doubling Data

Like other social-Web companies, such as Twitter, Facebook has never attained the reputation for technical innovation enjoyed by such Internet pioneers as Google. If Silicon Valley were a high school, the search company would be the quiet math genius who didn't excel socially but invented something indispensable. Facebook would be the annoying kid who started a club with such social momentum that people had to join whether they wanted to or not. In reality, Facebook employs hordes of talented software engineers (many poached from Google and other math-genius companies) to build and maintain its irresistible club. The technology built to support the Data Science Team's efforts is particularly innovative. The scale at which Facebook operates has led it to invent hardware and software that are the envy of other companies trying to adapt to the world of "big data."

In a kind of passing of the technological baton, Facebook built its data storage system by expanding the power of open-source software called Hadoop, which was inspired by work at Google and built at Yahoo. Hadoop can tame seemingly impossible computational tasks—like working on all the data Facebook's users have entrusted to it—by

Facebook is not above using its platform to tweak users' behavior, as it did by nudging them to register as organ donors. Unlike academic social scientists, Facebook's employees have a short path from an idea to an experiment on hundreds of millions of people.

spreading them across many machines inside a data center. But Hadoop wasn't built with data science in mind, and using it for that purpose requires specialized, unwieldy programming. Facebook's engineers solved that problem with the invention of Hive, open-source software that's now independent of Facebook and used by many other companies. Hive acts as a translation service, making it possible to query vast Hadoop data stores using relatively simple code. To cut down on computational demands, it can request random samples of an entire data set, a feature that's invaluable for companies swamped by data. Much of Facebook's data resides in one Hadoop store more than 100 petabytes (a million gigabytes) in size, says Sameet Agarwal, a director of engineering at Facebook who works on data infrastructure, and the quantity is growing exponentially. "Over the last few years we have more than doubled in size every year," he says. That means his team must constantly build more efficient systems.

All this has given Facebook a unique level of expertise, says Jeff Hammerbacher, Marlow's predecessor at Facebook, who initiated the company's effort to develop its own data storage and analysis technology. (He left Facebook in 2008 to found Cloudera, which develops Hadoop-based systems to manage large collections of data.) Most large businesses have paid established software companies such as Oracle a lot of money for data analysis and storage. But now, big companies are trying to understand how Facebook handles its enormous information trove on open-source systems, says Hammerbacher. "I recently spent the day at Fidelity helping them understand how the 'data scientist' role at Facebook was conceived ... and I've had the same discussion at countless other firms," he says.

As executives in every industry try to exploit the opportunities in "big data," the intense interest in Facebook's data technology suggests that its ad business may be just an offshoot of something much more valuable. The tools and techniques the company has developed to handle large volumes of information could become a product in their own right.

Mining for Gold

Facebook needs new sources of income to meet investors' expectations. Even after its disappointing IPO, it has a staggeringly high price-to-earnings ratio that can't be justified by the barrage of cheap ads the site now displays. Facebook's new campus in Menlo Park, California, previously inhabited by Sun Microsystems, makes that pressure tangible. The company's 3,500 employees rattle around in enough space for 6,600. I walked past expanses of empty desks in one building; another, next door, was completely uninhabited. A vacant lot waited nearby, presumably until someone invents a use of our data that will justify the expense of developing the space.

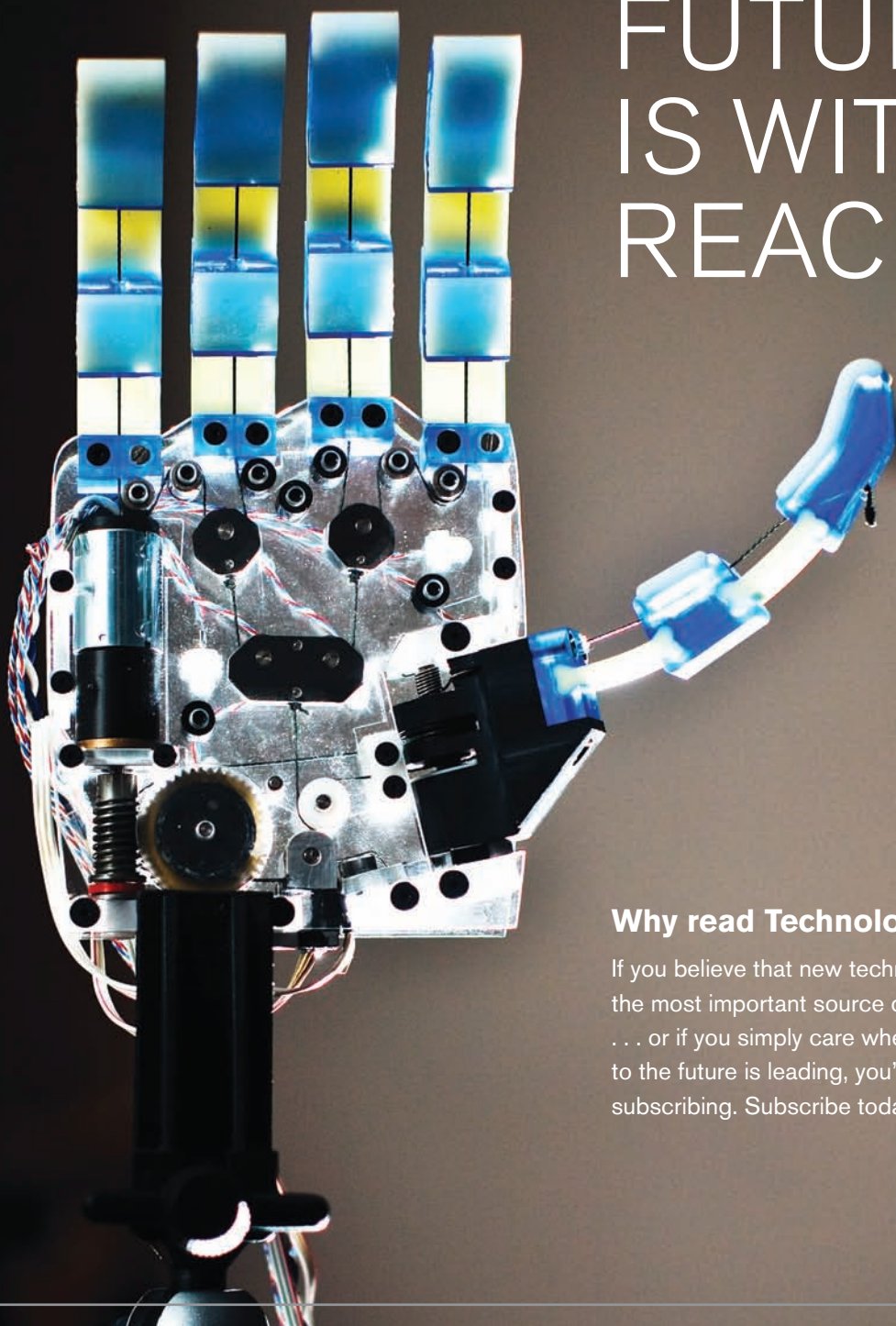
One potential use would be simply to sell insights mined from the information. DJ Patil, data scientist in residence with the venture capital firm Greylock Partners and previously leader of LinkedIn's data science team, believes Facebook could take inspiration from Gil Elbaz, the inventor of Google's AdSense ad business, which provides over a quarter of Google's revenue. He has moved on from advertising and now runs a fast-growing startup, Factual, that charges businesses to access large, carefully curated collections of data ranging from restaurant locations to celebrity body-mass indexes, which the company collects from free public sources and by buying private data sets. Factual cleans up data and makes the result available over the Internet as an on-demand knowledge store to be tapped by software, not humans. Customers use it to fill in the gaps in their own data and make smarter apps or services; for example, Facebook itself uses Factual for information about business locations. Patil points out that Facebook could become a data source in its own right, selling access to information compiled from the actions of its users. Such information, he says, could be the basis for almost any kind of business, such as online dating or charts of popular music. Assuming Facebook can take this step without upsetting users and regulators, it could be lucrative. An online store wishing to target its promotions, for example, could pay to use Facebook as a source of knowledge about which brands are most popular in which places, or how the popularity of certain products changes through the year.

Hammerbacher agrees that Facebook could sell its data science and points to its currently free Insights service for advertisers and website owners, which shows how their content is being shared on Facebook. That could become much more useful to businesses if Facebook added data obtained when its "Like" button tracks activity all over the Web, or demographic data or information about what people read on the site. There's precedent for offering such analytics for a fee: at the end of 2011 Google started charging $150,000 annually for a premium version of a service that analyzes a business's Web traffic.

Back at Facebook, Marlow isn't the one who makes decisions about what the company charges for, even if his work will shape them. Whatever happens, he says, the primary goal of his team is to support the well-being of the people who provide Facebook with their data, using it to make the service smarter. Along the way, he says, he and his colleagues will advance humanity's understanding of itself. That echoes Zuckerberg's often doubted but seemingly genuine belief that Facebook's job is to improve how the world communicates. Just don't ask yet exactly what that will entail. "It's hard to predict where we'll go, because we're at the very early stages of this science," says Marlow. "The number of potential things that we could ask of Facebook's data is enormous." tr

One potential use of Facebook's data storehouse would be to sell insights mined from it. Such information could be the basis for almost any kind of business. Assuming Facebook can do this without upsetting users and regulators, it could be lucrative.

Tom Simonite is *Technology Review*'s senior IT editor.



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These wind turbines under construction in Görmin, Germany, are among more than 22,000 installed in that country.

The Great German Energy Experiment



Germany has decided to pursue ambitious greenhouse-gas reductions—while closing down its nuclear plants. Can a heavily industrialized country power its economy with wind turbines and solar panels?

By David Talbot

Along a rural road in the western German state of North Rhine–Westphalia lives a farmer named Norbert Leurs. An affable 36-year-old with callused hands, he has two young children and until recently pursued an unremarkable line of work: raising potatoes and pigs. But his newest businesses point to an extraordinary shift in the energy policies of Europe's largest economy. In 2003, a small wind company erected a 70-meter turbine, one of some 22,000 in hundreds of wind farms dotting the German countryside, on a piece of Leurs's potato patch. Leurs gets a 6 percent cut of the electricity sales, which comes to about $9,500 a year. He's considering adding two or three more turbines, each twice as tall as the first.

The profits from those turbines are modest next to what he stands to make on solar panels. In 2005 Leurs learned that the government was requiring the local utility to pay high prices for rooftop solar power. He took out loans, and in stages over the next seven years, he covered his piggery, barn, and house with solar panels—never mind that the skies are often gray and his roofs aren't all optimally oriented. From the resulting 690-kilowatt installation he now collects $280,000 a year, and he expects over $2 million in profits after he pays off his loans.

Stories like Leurs's help explain how Germany was able to produce 20 percent of its electricity from renewable sources in

2011, up from 6 percent in 2000. Germany has guaranteed high prices for wind, solar, biomass, and hydroelectric power, tacking the costs onto electric bills. And players like Leurs and the small power company that built his turbine have installed off-the-shelf technology and locked in profits. For them, it has been remarkably easy being green.

What's coming next won't be so easy. In 2010, the German government declared that it would undertake what has popularly come to be called an *Energiewende*—an energy turn, or energy revolution. This switch from fossil fuels to renewable energy is the most ambitious ever attempted by a heavily industrialized country: it aims to cut greenhouse-gas emissions 40 percent from 1990 levels by 2020, and 80 percent by midcentury. The goal was challenging, but it was made somewhat easier by the fact that Germany already generated more than 20 percent of its electricity from nuclear power, which produces almost no greenhouse gases. Then last year, responding to public concern over the post-tsunami nuclear disaster in Fukushima, Japan, Chancellor Angela Merkel ordered the eight oldest German nuclear plants shut down right away. A few months later, the government finalized a plan to shut the remaining nine by 2022. Now the *Energiewende* includes a turn away from Germany's biggest source of low-carbon electricity.

Germany has set itself up for a grand experiment that could have repercussions for all of Europe, which depends heavily on German economic strength. The country must build and use renewable energy technologies at unprecedented scales, at enormous but uncertain cost, while reducing energy use. And it must pull it all off without undercutting industry, which relies on reasonably priced, reliable power. "In a sense, the *Energiewende* is a political statement without a technical solution," says Stephan Reimelt, CEO of GE Energy Germany. "Germany is forcing itself toward innovation. What this generates is a large industrial laboratory at a size which has never been done before. We will have to try a lot of different technologies to get there."

The major players in the German energy industry are pursuing several strategies at once. To help replace nuclear power, they are racing to install huge wind farms far off the German coast in the North Sea; new transmission infrastructure is being planned to get the power to Germany's industrial regions. At the same time, companies such as Siemens, GE, and RWE, Germany's biggest power producer, are looking for ways to keep factories humming during lulls in wind and solar power. They are searching for cheap, large-scale forms of power storage and hoping that computers can intelligently coördinate what could be millions of distributed power sources.

Estimates of what the transition will cost vary widely, depending in part on how fast new technology can be introduced and its price lowered. Various economic think tanks predict that the country will spend somewhere between $125 billion and $250 billion on infrastructure expansion and subsidies in the next eight years—between 3.5 and 7 percent of Germany's 2011 GDP. The long-term costs, including the expense of decommissioning nuclear power plants, will be far higher.

Germany has already incurred significant costs. Each monthly electric bill carries a renewable-energy surcharge of about 15 percent (heavy industry is exempt). Wholesale electricity prices have jumped approximately 10 percent since the eight nuclear plants were shut. The German grid is strained as never before. And—ironically, given the *Energiewende*'s goal of reducing greenhouse-gas emissions—the decision to close the nuclear plants has increased reliance on coal-fired power plants.



At dockyards near the North Sea port of Rostock, Germany, Siemens is building a massive platform that will house equipment for managing power from wind farms far offshore.

Despite the costs, Germany could greatly benefit from its grand experiment. In the past decade, the country has nurtured not only wind and solar power but less-heralded energy technologies such as management software and efficient industrial processes. Taken together, these "green" technologies have created an export industry that's worth $12 billion—and is poised for still more growth, according to Miranda Schreurs, director of the Environmental Policy Research Center at the Berlin Free University. Government policies could provide further incentives to develop and deploy new technologies. "That is know-how that you can sell," Schreurs says. "The way for Germany to compete in the long run is to become the most energy-efficient and resource-efficient market, and to expand on an export market in the process."

COURTESY OF SIEMENS; PREVIOUS SPREAD: SEAN GALLUP/GETTY

If Germany succeeds in making the transition, it could provide a workable blueprint for other industrial nations, many of which are also likely to face pressures to transform their energy consumption. "This *Energiewende* is being watched very closely. If it works in Germany, it will be a template for other countries," says Graham Weale, chief economist at RWE, which is grappling with how to shut its nuclear power plants while keeping the lights on. "If it doesn't, it will be very damaging to the German economy and that of Europe."

Choke Points

In the city of Erlangen, 20 kilometers north of Nuremberg, tight security greets visitors to the complex of industrial buildings that house the labs and factories of the energy giant Siemens, one of several contractors contributing to the *Energiewende*. One of these buildings literally hums with power—30 megawatts' worth. Inside is a giant steel and copper machine that converts AC power to DC at a massive scale; it's destined for installation on offshore platforms that must withstand harsh North Sea storms for decades.

Germany needs this technology because it's looking for the steadiest source of wind it can find, and that's found far offshore—so far that the standard AC lines for transmitting power won't work. To date, Germany has installed only about 500 megawatts of offshore wind power, all within 90 kilometers of land, in water less than 40 meters deep. Now energy companies are planning to install 10,000 megawatts of wind power as far offshore as 160 kilometers, at depths of up to 70 meters. Several 10,000- to 20,000-ton offshore substations will convert gigawatts of AC output to DC, which can span such distances without large energy losses. "There is nowhere in the world where this has been done—building offshore grids and offshore connections in this way and in this amount," says Lex Hartman, director of corporate development at Tennet, the Dutch grid company in charge of parts of Germany's megascale North Sea effort.

Of course, all this just gets the power to the beach. The electricity needs to traverse Germany to reach the major industrial centers in the country's south. Some 3,800 kilometers of new power lines are needed, but only around 200 have been built, with reluctant landowners and regional politicians stalling progress and creating choke points. The delays and the novel technologies make the German offshore wind program a huge gamble all by itself. "Nobody really knows what the *Energiewende* will cost," says Karen Pittel, an energy economist at the University of Munich. "But especially those wind farms—they are more or less pilot projects."

"This *Energiewende* is being watched very closely. If it works in Germany, it will be a template for other countries. If it doesn't, it will be very damaging to the German economy."

The uncertainties don't stop there. Even with current levels of wind power, on windy days grid operators must shut turbines down because there's nowhere to put the power. When a cloud bank rolls over southern Germany on an otherwise sunny day, the output of the region's many photovoltaic panels can drop by hundreds of megawatts; the effect is like hitting the off switch on a moderate-size coal-fired power plant, increasing the threat of blackouts.

Without enough cheap, reliable power to support the high-technology industry and the transportation system, Germany's economy—and that of Europe as a whole—could be in trouble. Already some German firms are building new manufacturing facilities elsewhere; for example, last year the chemical producer Wacker Chemie decided to build a polysilicon plant in Tennessee, partly because energy costs in Germany were so high. Weale says, "The quality of the supply would only have to deteriorate a little bit and it would be quite serious for this high-technology industry. We've already seen, even without the lights going out, that industry is getting nervous."

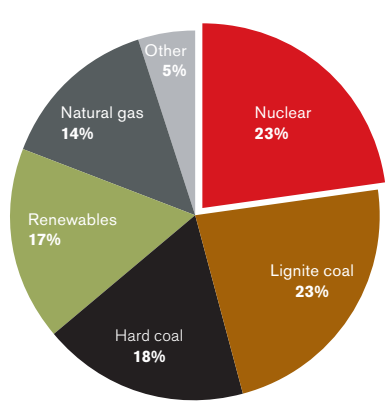
To avoid catastrophe, Germany will have to start deploying storage technologies and load-balancing strategies at far larger scales. The country today has 31 pumped-storage power plants, which force water into uphill reservoirs at night and then use the downhill flow to spin turbines to generate power. Altogether, they can store 38 gigawatt-hours' worth of electricity. That might sound like a lot, but it's less than 90 minutes of peak output from Germany's wind farms.

Batteries might help, but so far costs are too high for them to play more than a niche role. In another building in Erlangen, Siemens is building tractor-trailer-size batteries based on three different lithium-ion technologies. Each could power 40 German houses for a day, but the batteries are too expensive to use for backup power. Instead, high-tech manufacturers are likely to use them to ride out brownouts with, say, a 15-minute, eight-megawatt jolt so that specialized equipment won't need costly restart procedures. Prices would need to fall by at least half before lithium-ion batteries could provide an economical way to store hours of excess power from wind turbines.

Other storage technologies are being developed but are still probably years from being practical, if they ever will be. One new technology at Siemens, for example, produces hydrogen by using surplus electricity to split water molecules. But it is experimental and, at this stage, expensive.

Germany's Electricity Generation in 2010

Before nuclear plant closings



SOURCE: FEDERAL ASSOCIATION OF THE ELECTRICITY AND WATER INDUSTRY

INFOGRAPHICS.COM

Inevitably, some hot July week will come when a high-pressure system stalls over Europe, stilling turbines just when sunburned Germans reach for their air conditioners. Until large-scale, cheap storage is available, gas power plants, which can start up quickly and efficiently, will be the most practical way to cope with these situations. But there's little incentive to build such plants. Owners of gas plants meant to meet peak power needs can no longer count on running for a certain number of hours, since the need will no longer fall on predictable workday afternoons but come and go with the sun and wind. Says Ottmar Edenhofer, chief economist at the Potsdam Institute for Climate Impact Research, "The design of the electricity market will change fundamentally. You have fluctuating demand, and at the same time a fluctuating supply. The linkage and the interplay in these two dimensions has become the subject of intense research. There could be new and emerging market failures."

The goal is to use software to transform thousands of renewable energy sources, each of which alone is unreliable, into a vast network that utilities can depend on.

Virtual Power

Duisburg is a gritty town just west of Essen, a major World War II munitions manufacturing center that was reduced to rubble by Allied bombing. This is where RWE, one of Germany's four major utilities, is working at the frontier of another crucial technology: virtual power plants, in which software intelligently controls vast numbers of small power sources (and, eventually, distributed storage sites) to coördinate their output for sale on energy markets. The goal is to transform thousands of renewable energy sources, each of which alone is unreliable, into a vast network that utilities can depend on. It's a dazzling concept, but one in its infancy.

Inside a lab that sits in front of a Nazi-built bomb shelter shaped like a pointed witch's hat, RWE researchers are testing a dozen gas-fired boilers and fuel cells designed to generate both heat and electricity. In theory, utilities could call on hundreds of thousands of home units—and larger ones powering apartment or office buildings—to generate extra electricity for the grid in a pinch. As much as 5 percent of Germany's electricity could be produced this way—about the amount utilities expect to draw from the new offshore wind farms.

Reaching that point could take decades as homeowners and businesses gradually replace their existing boilers and the infrastructure is put in place to synchronize hundreds of thousands of power sources. But an hour east of Duisburg, in a 1960s-era office building on the edge of Dortmund, engineers are testing a more modest network as a starting point. A basement server room functions as a communications hub for 120 small generating stations that together produce 160 megawatts of electricity from renewable sources—mostly wind but also biomass and solar. Software takes weather predictions into account and assembles a block of renewable electricity from wind and solar, switching the biogas plants on and off as needed to balance the fluctuating output and create a block of stable power.

Early projects like this one are stepping-stones toward more sophisticated systems that include demand management: utilities would compensate customers for agreeing to have their power consumption automatically curtailed during times of peak demand. Someday the systems could also draw power from the batteries of parked electric cars, or store excess power in them, to compensate for shifts in the wind.

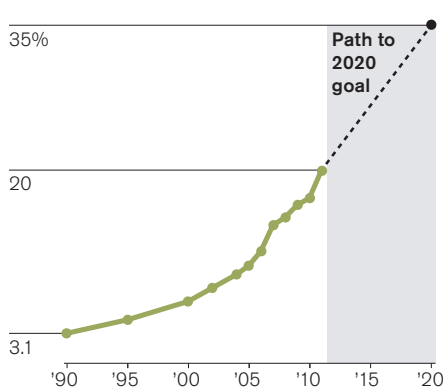
GE and other companies are pursuing such concepts, too. "Today what we know is that the energy market will be decentralized; it will be a fragmented market," says Reimelt, of GE. "Before, we had four utility companies. Today we have 350 companies generating power, going up to a thousand, and going up to a million if you count everyone with a solar panel on the roof. So one of the trends that we see is that there must be less emphasis on power generation and more on power management."

Baffled in Bavaria

The floor-to-ceiling windows behind the desk of Wolfgang Mayer, the burgermeister of the small Bavarian town of Gundremmingen, provide a commanding view. A

Germany's Progress So Far

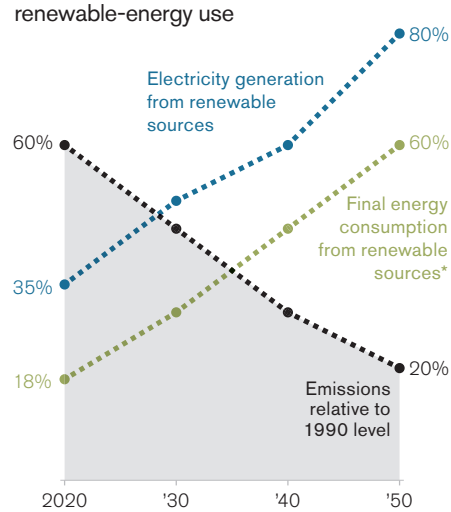
Percentage of the country's electricity that comes from renewable sources



SOURCE: FEDERAL MINISTRY FOR THE ENVIRONMENT, NATURE CONSERVATION, AND NUCLEAR SAFETY

Charting the Energy Turn

Goals for greenhouse-gas emissions and renewable-energy use



*Including electricity, transportation fuels, and heat

SOURCE: FEDERAL MINISTRY FOR THE ENVIRONMENT, NATURE CONSERVATION, AND NUCLEAR SAFETY



Cooling towers at a nuclear power plant in Gundremmingen are visible behind homes whose owners are taking advantage of solar-power subsidies. The plant is marked for closure.

mile away stand the twin cooling towers of the Gundremmingen Nuclear Power Station Units B and C, which together are the largest source of nuclear power in Germany. Nicely situated halfway between the industrial centers of Stuttgart and Munich, the plant has the capacity to produce 2.6 gigawatts of power. Mayer is confounded by the *Energiewende*, which threatens hundreds of jobs in town and could hurt tax revenues. "They say 2017 to shut down Unit B, and 2021 for Unit C," he says, motioning toward the plant. "But they were the same time starting up in 1989! A normal person cannot understand. What is the logic?"

Mayer is not alone in his bafflement. There is much about the current policy that arguably isn't logical. In the short term at least, the decision to close the nuclear plants means that the *Energiewende* will actually push utilities to rely more heavily on coal. Last year, for example, RWE fired up two long-planned new boilers at an existing facility near the Belgian border that burns the dirtiest fossil fuel of them all: brown lignite coal. Though these boilers are cleaner than the ones they're replacing, the coal plant is the largest of its kind in the world, and it's going full blast these days to keep up with power demand.

"If you close eight nuclear plants, which were carbon-free, overnight, you will increase carbon emissions," Weale says. "One will have to be more reliant on coal than was previously expected. It may be hard to reduce CO_2 emissions as quickly as one would like." Decisions made now about what kinds of power plants to install will have repercussions for decades, he says: "You can't make sudden changes from one asset to another."

A second problem is that even when it comes to alternative energy sources, Germany doesn't reward carbon dioxide reduction. Rather, its policy establishes well-defined subsidies for specific technologies: a kilowatt-hour of solar power is rewarded more than power from offshore wind, which in turn earns more than power from onshore wind. Even though solar subsidies have been reduced to rates far lower than the ones Leurs locked in, solar power still pays the highest rates. If reducing emissions were the focus, however, more money would be directed toward reducing energy use. "If you could choose the optimal instruments, focusing on those areas first where you can achieve your goals most inexpensively, you would focus not so much on renewables but much more on efficiency," says Pittel, the energy economist from Munich.

The current subsidies also don't encourage innovation as much as they make existing technologies profitable. There's little incentive to, say, develop radically new photovoltaic technologies, even though these might ultimately be the only way to make unsubsidized solar power cheap enough to compete with fossil fuels.

To some German economists, the country's energy policy is simply wrong-headed. Hans-Werner Sinn, president of the Ifo Institute for Economic Research at the University of Munich, is especially scathing. "The *Energiewende* is a turn into nowhereland, because the green technologies are just not sufficient to provide a replacement for modern society's energy needs," he says. "It is wrong to shut down the atomic power plants, because this is a cheap source of energy, and wind and solar power are by no means able to provide a replacement. They are much more expensive, and the energy that comes out is of inferior quality. Energy-intensive industries will move out, and the competitiveness of the German manufacturing sector will be reduced or wages will be depressed."

German politicians, of course, are betting that Sinn is wrong. And plenty of encouraging signs argue against his pessimism. The cost of solar panels has dropped sharply, which means that solar power may become more competitive. Battery costs may follow suit. If fossil fuels continue to become more expensive, renewable power sources will look more attractive. "Forty years is a long time, and one is continuously being surprised by favorable technological developments—for example, the way in which the price of solar cells is coming down," Weale says. "From my point of view, I want to emphasize how challenging the *Energiewende* is. At the moment, it's looking difficult. But with the right incentives, one can have good reason to believe that technological progress will be a lot faster than we currently expect." tr

David Talbot, *Technology Review*'s chief correspondent, wrote about Kenya's startup culture in March.

OPPOSITE: INFOGRAPHICS.COM; DAVID TALBOT/TECHNOLOGY REVIEW



George Church

BIOLOGY'S MASTER PROGRAMMERS

For more than a decade, synthetic biologists have promised to revolutionize the way we produce fuels, chemicals, and pharmaceuticals. It turns out, however, that programming new life forms is not so easy. Now some of these same scientists are turning back to nature for inspiration.

By MICHAEL WALDHOLZ

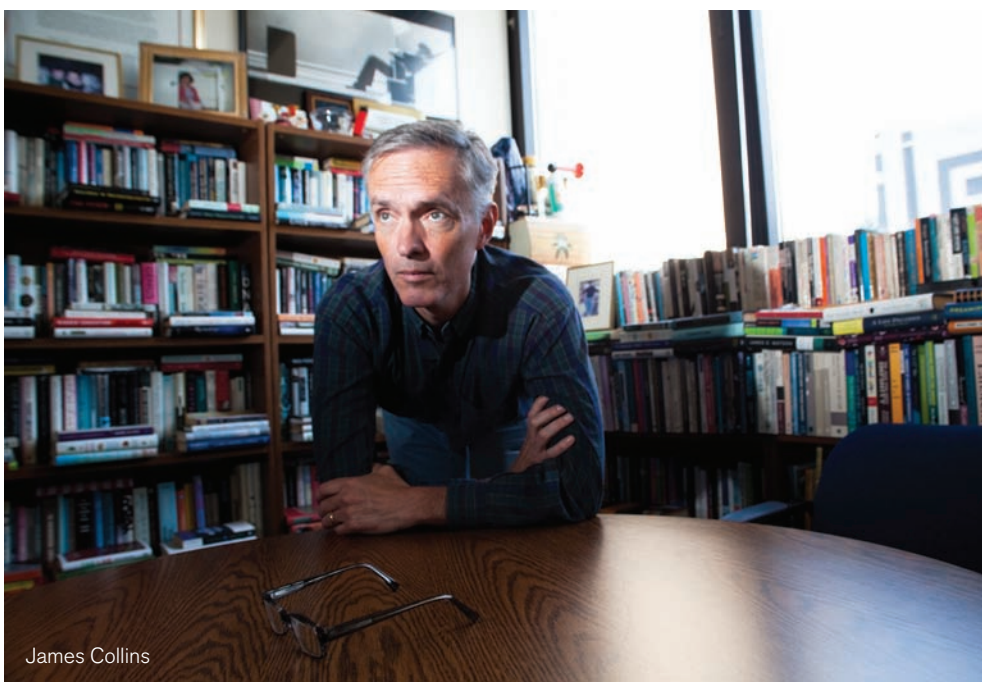
Photographs by Mark Ostow

George Church is an imposing figure—over six feet tall, with a large, rectangular face bordered by a brown and silver nest of beard and topped by a thick mop of hair. Since the mid-1980s Church has played a pioneering role in the development of DNA sequencing, helping—among his other achievements—to organize the Human Genome Project. To reach his office at Harvard Medical School, one enters a laboratory humming with many of the more than 50 graduate students and postdoctoral fellows over whom Church rules as director of the school's Center for Computational Genetics. Passing through an anteroom of assistants, I find Church at his desk, his back to me, hunched over a notebook computer that makes him look even larger than he is.

Church looms especially large these days because of his role as one of the most influential figures in synthetic biology, an ambitious and radical approach to genetic engineering that attempts to create novel biological entities—everything from enzymes to cells and microbes—by combining the expertise of biology and engineering. He and his lab are credited with many of the advances in harnessing and synthesizing DNA that now help other researchers modify microörganisms to create new fuels and medical treatments. When I ask Church to describe what tangible impact synthetic biology will have on everyday life, he leans back in his chair, clasps his hands behind his head, and says, "It will change everything. People are going to live healthier a lot longer because of synthetic biology. You can count on it."

Such grandiosity is not uncommon among the practitioners of synthetic biology. Ever since Church and a few other researchers began to combine biology and engineering a dozen years ago, they have promised it would "change everything." And no wonder. The very idea of synthetic biology is to purposefully engineer the DNA of living things so that they can accomplish tasks they don't carry out in nature. Although genetic engineering has been going on since the 1970s, a rapid drop in the cost of decoding and synthesizing DNA, combined with a vast increase in computer power and an influx into biology labs of engineers and computer scientists, has led to a fundamental change in how thoroughly and swiftly an organism's genetics can be modified. Church says the technology will eventually lead to all manner of breakthroughs: we will be able to replace diseased tissues and organs by reprogramming cells to make new ones, create novel microbes that efficiently secrete fuels and other chemicals, and fashion DNA switches that turn on the right genes inside a patient's cells to prevent arteries from getting clogged.

Even though some of these applications are years from reality, Church has a way of tossing off such predictions matter-of-factly. And it's easy to see why he's optimistic. The cost of both decoding DNA and synthesizing new DNA strands, he has calculated, is falling about five times as fast as computing power is increasing under Moore's Law, which has accurately predicted that chip performance will double roughly every two years. Those involved in synthetic biology, who often favor computer analogies, might say it's becoming exponentially easier to read from, and write into, the source code of life. These underlying technology trends, says Church, are leading to an explosion in experimentation of a sort that would have been inconceivable only a few years ago.


James Collins

Up to now, it's proved stubbornly difficult to turn synthetic biology into a practical technology that can create products like cheap biofuels. Scientists have found that the "code of life" is far more complex and difficult to crack than anyone might have imagined a decade ago. What's more, while rewriting the code is easier than ever, getting it right isn't. Researchers and entrepreneurs have found ways to coax bacteria or yeast to make many useful compounds, but it has been difficult to optimize such processes so that the microbes produce significant quantities efficiently enough to compete with existing commercial products.

Church is characteristically undeterred. At 57, he has survived cancer and a heart attack, and he suffers from both dyslexia and narcolepsy; before I visited him, one of his colleagues warned that I shouldn't be surprised if he fell asleep on me. But he has founded or taken an advisory role in more than 50 startup companies—and he stayed awake throughout our time together, apparently excited to describe how his lab has found ways to take advantage of ultrafast sequencing and other tools to greatly speed up synthetic biology. Among its many projects, Church's lab has invented a technique for rapidly synthesizing multiple novel strings of DNA and introducing them simultaneously into a bacterial genome. In one experiment, researchers created four billion variants of *E. coli* in a single day. After three days, they found variants of the bacteria in which production of a desired chemical was increased fivefold.

The idea, Church explains, is to sort through the variations to find "an occasional hopeful monster, just as evolution has done for millions of years." By mimicking in lab experiments what takes eons in nature, he says, he is radically improving the odds of finding ways to make microbes not just do new things but do them efficiently.

A DNA Turn-On

In some ways, the difficulties researchers have faced making new, more useful life forms shouldn't come as a surprise. Indeed, a lesson of genome research over the last few decades is that no matter how elegantly compact the DNA code is, the biology it gives rise to is consistently more complex than anyone anticipated. When I began reporting the early days of gene discovery 30 years ago, biologists, as they often do, thought reductively. When they found a gene involved in disease, the discovery made headlines. Scientists said they believed that potent new medicines could soon deactivate

malfunctioning versions of genes, or that gene therapy could be used to replace them with healthy versions in the body.

The early biotech companies also employed a one-gene-at-a-time approach. Companies would locate the gene that made a particular protein, such as insulin; then, using gene-splicing technology first developed in the 1970s, they would snip open the DNA of a bacterium and slide in the insulin-making gene. It's a technology that has led to today's biotech industry.

Yet some scoffed at the idea that such techniques involved any real engineering. "To us, it was no more engineering than changing a red light bulb with a green light bulb," says James Collins, a Boston University bioengineer who is credited with helping create the field of synthetic biology in 2000. "Many of us thought that working at the single-gene level was just a starting point, that we really needed to figure out how all these newly identified genes arising from the Human Genome Project fit into networks, pathways, and circuits inside the cell." By comparison, says Collins, "synthetic biology is genetic engineering on steroids."

> "Many of us thought that working at the single-gene level was just a starting point, that we really needed to figure out how all these newly identified genes arising from the Human Genome Project fit into networks, pathways, and circuits inside the cell." *—James Collins*

I met Collins on a rainy winter day in his office on the BU campus. He's an enthusiastic storyteller, full of details, digressions, and gossip. And at 46, he has lived through the conception and birth of synthetic biology. Collins told me how he and other engineers in the late 1990s felt left out of what appeared to be the most important science of the time, the sequencing of the human genome. It seemed that every other cover of the journal *Science* was hailing some new gene breakthrough. But with a slew of unanalyzed DNA data piling up in computer databases, it was becoming clear that biologists didn't know how genetic parts worked together. Collins says, "We had felt like we were kids outside a candy store. So we figured, 'How can we get in?'"

Collins wanted to study cellular processes by constructing gene networks rather than taking them apart. As a first step, he built a biological toggle circuit. A toggle is a mechanism with two possible states—in the case of a light switch, on or off. In the switch he and his colleagues built from DNA, two genes next to each other in a bacterial genome both produced proteins when they were "on." But Collins set things up so that each protein would block production of the other—if gene 1 was on, it would keep gene 2 off, and vice versa. With the aid of chemicals or a thermal pulse, Collins could flip between the two states.

The DNA toggle switch was analogous to an electronic transistor, able to store a single bit of information. It was also an engineered example of the kind of feedback loop that often determines whether cells grow, divide, or die. "The idea that you could build a circuit out of biological parts helped launch the field of synthetic biology," says Collins. The results were published in January 2000.

Soon Collins's toggle was joined by an expanding list of DNA circuits, including biosensors, oscillators, bacterial calculators, and similar molecular gadgetry. Researchers even established a Registry of Standard Biological Parts: 7,100 different DNA structures are available to order. Scientists were excited by the idea that biology might be modular and predictable, like something made with Lego blocks or computer code. Many scrambled to found companies that they hoped would commercialize the technology to produce fuels, drugs, or other products.

While comparisons to computer programming inspired many researchers, however, these tended to oversimplify biology, which has not proved entirely predictable. Furthermore, the claims that some synthetic-biology companies made now appear to have been overly optimistic, Collins says.

Indeed, Collins believes the rush to commercialize has been a mistake. "The companies are sucking the oxygen out of the field," he says, noting that they have hired scores of geneticists from university labs. They're "scooping up our seed corn, the young researchers who should be staying in academic labs working through new ways to engineer biology." He worries that the race to apply the new technology means "there's going to be a number of biotech carcasses on the side of the road in the near future."

Not even George Church has been immune: Codon Devices, a company he cofounded in 2004, was forced to shut down. Codon, in Church's words, was established to be the Intel of the bioengineering industry, building ready-made synthetic-biological modules that researchers could use to redesign, say, a yeast. The company "burned through its cash," he laments.

Nature's Code

Church hopes his latest enterprise avoids a similar fate. Called Warp Drive Bio, the company combines computer science, chemistry, and genetic engineering in ways that would not have been possible until recently. It aims to use ultrafast DNA sequencing and synthetic-biology techniques, some of which Church pioneered, to hunt for potential medicines by scouring the DNA of millions of environmental samples that drug companies have collected and stored over several decades. Warp Drive is, in effect, searching for genetic parts that nature has already programmed to make particularly potent, useful chemicals. Church's technology will be used to generate copies of those parts, incorporate them into bacteria, and optimize their performance. Then the bacteria can be used to produce chemicals that, if all goes according to plan, have new and interesting therapeutic properties.

Warp Drive, which was launched in January, employs fewer than a dozen full-time staffers and occupies only about 1,000 square

feet of office and lab space in Cambridge, Massachusetts. But the startup, which has raised $125 million in investments, has already formed a strategic partnership with the French pharmaceutical company Sanofi. If Warp Drive Bio meets certain milestones, it has the option to demand that Sanofi purchase the company for $1 billion or more. The deal was struck after Warp Drive's principal founder, Harvard biochemist Gregory Verdine, was invited to Paris last May and gave a two-hour presentation that had Sanofi's head of research, Elias Zerhouni, and several other staffers crowding around his laptop.

Zerhouni, a former head of the U.S. National Institutes of Health, immediately grasped the novelty and potential of Warp Drive's idea for sifting through nature's existing stockpile of DNA parts. "We've been plagued by a lack of creativity," he says. "It made sense to give them the resources they need."

Verdine's insight is that nature is particularly adept at creating chemicals that act safely and precisely on a desired biological target. He says that half the small-molecule drugs developed over the last 30 to 35 years have been natural products or derivatives of such products. "It struck me that probably something useful in evolution helped tailor properties in these compounds that made them better suited to work in complex cell systems like the human body," he says. "Nature seemed to have already engineered in complexities that drug chemists don't understand."


Gregory Verdine

> "It struck me that probably something useful in evolution helped tailor properties in these compounds that made them better suited to work in complex cell systems like the human body." —*Gregory Verdine*

I interviewed Verdine in a spare room, no bigger than a walk-in closet, just outside Warp Drive's lab in a converted book factory in Cambridge. If Church and Collins are intent on creating new synthetic parts and bioengineering techniques, Verdine is hoping to use many of the same techniques to unwrap the mysteries of how nature does it. Over the decades, he explained to me, pharmaceutical researchers have collected and stored tens of thousands, and more likely millions, of environmental samples, including dirt and pond scum. The idea was to discover some potent chemical in these mixtures by dripping extracts onto cancer cells or into petri dishes of bacteria. But that process is laborious and subject to chance. Most drug companies have scaled back such research.

The answer, Verdine decided, was to search for DNA instead. Given the plummeting cost of DNA sequencing, it's now feasible to simply decode all the genetic material present in, say, a drop of pond water teeming with microörganisms. Verdine says many of the natural drugs that have already been identified have similar DNA signatures—clusters of genes that often occur together in a microbe's genome. The trick, he adds, is to scan the samples' DNA to locate familiar-looking clusters that might be recipes for synthesizing a natural product—ideally, an important one that hasn't been found before.

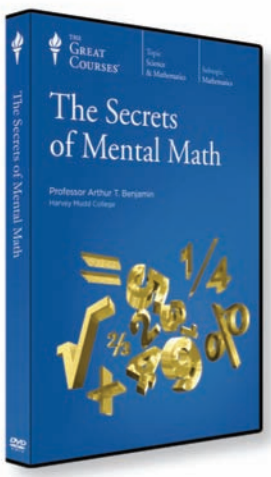
Once identified, the DNA sequences will need to be engineered into a bacterium so that the company can produce the chemical and study the potential drugs. This is where the synthetic-biology techniques developed by Church will be crucial: in transforming the code into actual compounds. "We use genomics and informatics to find a gene cluster. But that's an information unit," Verdine says. "We have to get the molecule. Synthetic biology involves coaxing the cluster into biosynthetic factories, which then produce the molecules. If we don't have the molecule, the cluster is useless."

The idea of resorting to nature's stockpile for parts, Church says, is "ironic and interesting" given synthetic biology's interest in producing entirely new DNA circuits and, ultimately, generating entire organisms from scratch. Researchers today may alter, copy, and paste DNA with increasing ease, but they still struggle when it comes to actually composing DNA that does anything useful. They are still editing nature's code and learning from it. It turns out that for now, nature is still the best programmer. tr

Michael Waldholz is a former managing editor at *Bloomberg News*, where he oversaw the publication's coverage of health and science. Previously, he was a reporter and news editor at the *Wall Street Journal*. His books include *Curing Cancer* and *Genome*, which was published in 1990.

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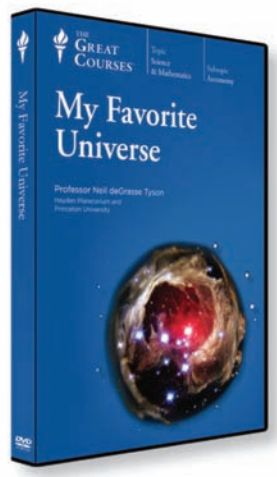
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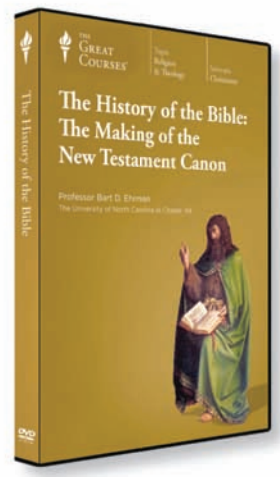
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Internet ads are a $70 billion business that is built on data about you. Has it gone too far? *TR* examines the business models and technologies that are determining the value of privacy. Find the full report at technologyreview.com/business.

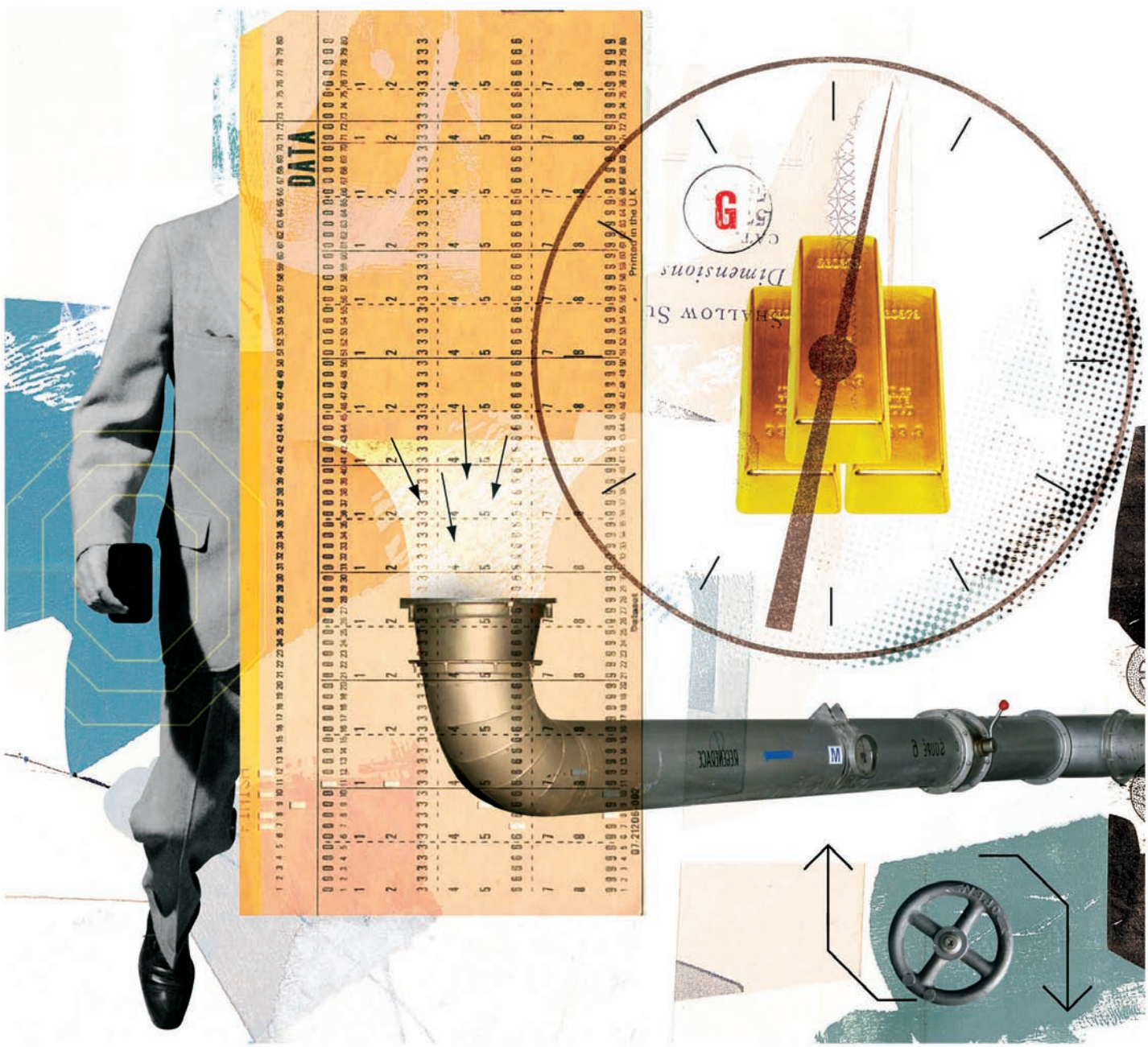
INCLUDING:

High Stakes in Internet Tracking

The Curious Case of Internet Privacy

Keeping Things Private at Microsoft

A Dollar for Your Data



STUART BRADFORD

THE BIG QUESTION

High Stakes in Internet Tracking

Will "Do Not Track" kill off innovation along with targeted advertising?

By ANTONIO REGALADO

An Amazon ad for a book by science fiction writer Cory Doctorow recently appeared on my computer screen. "What a coincidence!" I thought naïvely. I'd been reading Doctorow's item on Internet privacy *(see opposite page)* and had looked up his past writing. That was all it took for a crowd of ads to start following me.

The business story of our age is how the Internet connects us. Part of being connected by technology is having an identity. It used to be a phone number. On the network, it's an IP address or the browser cookies that tell other computers who you are.

The problem now is that anyone can use these tools to track you. Gary Kovacs, CEO of Mozilla, recently demonstrated Collusion, an add-on to the Firefox Web browser that lets you see who those anyones are. Kovacs says a who-knows-who of 150 entities were tracking his activity after one day. This crowd of hucksters and ad networks was following his nine-year-old daughter, too.

Some people think tracking is creepy. Kovacs is one of them. He says when we go on the Internet we are like Hansel and Gretel leaving information breadcrumbs—birthdays, financial histories, and relationship status—"everywhere as we travel through the digital woods."

It's a scary story, but what are we really worried about? In our age of satellite imagery and Street View and data mashups, knowledge is getting more and more granular. It's becoming harder to be private, to be "secluded" in the most literal sense of the word. There's now a gathering movement to give people a choice. Earlier this year President Barack Obama endorsed "Do Not Track," a browser technology meant to limit tracking and potentially prevent ads like Amazon's that target you on the basis of your past Web surfing.

Such ads are a multibillion-dollar business. All the same, Microsoft's chief privacy officer says the forthcoming Internet Explorer 10 will be the first browser to have "Do Not Track" turned on by default. For Microsoft, trust is the greater competitive advantage.

Before you cheer, you might ask if there is any real harm in commercial tracking. Despite the hand-wringing, it's not so easy to find people hurt by collection of their personal data. Just ask the trial lawyers who have been bringing a ballooning number of privacy suits. At first, courts rebuffed their class-action claims; they could not show "injury in fact."

Recently, regulators have taken a more expansive view. The Federal Trade Commission now says privacy-related harms needn't be economic or physical but can also include practices that "unexpectedly reveal previously private information" like purchasing habits. That is opening the legal floodgates. Facebook faces a class action that alleges it violated wiretap laws and asks for damages of $15 billion—about what the company raised in its IPO. The *National Law Review* calculates that Google could owe *$800 billion* in fines to the government for circumventing the Safari browser's privacy settings.

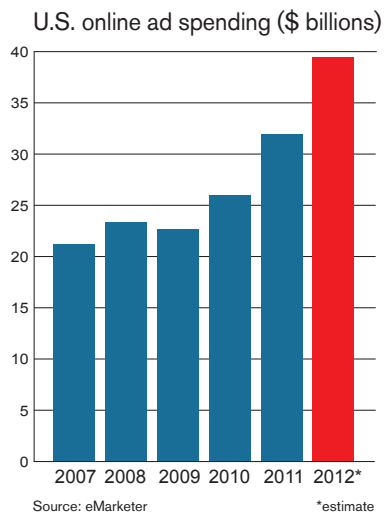
Now that lawyers are involved, you'd be right to wonder if something innovative will end up in the crosshairs. For instance, a 12-person Data Science Team at Facebook is sitting on the largest trove of data ever collected on human behavior *(see "What Facebook Knows," p. 42)*. This could yield something big—even if no one yet knows what. It will definitely result in more targeted ads. But so what? The fact is, if you phrase the question right, many consumers will admit they actually want targeted ads.

Now that I think about it, I might just buy that Doctorow book. Thanks for the connection, Amazon. BI

Antonio Regalado is *Technology Review*'s senior editor for business.

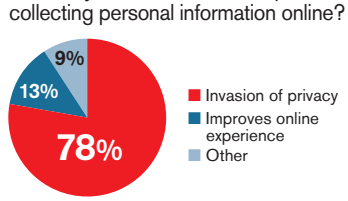
DATA MARKET

The growth of online advertising is raising privacy questions.



Source: eMarketer *estimate

What is your view about companies collecting personal information online?



On a scale of 0 to 10, which companies do you trust with your personal information?

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Google	3.8
LinkedIn	3.0
Facebook	2.7
Twitter	2.4

Source: USC/*L.A.Times* poll of 1,500 California voters



PRESERVATIONIST
Cory Doctorow working in the privacy of his home office in London.

JONATHAN WORTH/CREATIVE COMMONS

OPINION

The Curious Case of Internet Privacy

Free services in exchange for personal information. That's the "privacy bargain" we all strike on the Web. It could be the worst deal ever.

By CORY DOCTOROW

Here's a story you've heard about the Internet: we trade our privacy for services. The idea is that your private information is less valuable to you than it is to the firms that siphon it out of your browser as you navigate the Web. They know what to do with it to turn it into value—for them and for you. This story has taken on mythic proportions, and no wonder, since it has billions of dollars riding on it.

But if it's a bargain, it's a curious, one-sided arrangement. To understand the kind of deal you make with your privacy a hundred times a day, please read and agree with the following:

> *By reading this agreement, you give* Technology Review *and its partners the unlimited right to intercept and examine your reading choices from this day forward, to sell the insights gleaned thereby, and to retain that information in perpetuity and supply it without limitation to any third party.*

Actually, the text above is not exactly analogous to the terms on which we bargain with every mouse click. To really polish the analogy, I'd have to ask this magazine to hide that text in the margin of one of the back pages. And I'd have to end it with *This agreement is subject to change at any time.* What we agree to participate in on the Internet isn't a negotiated trade; it's a smorgasbord, and intimate facts of your life (your location, your interests, your friends) are the buffet.

Why do we seem to value privacy so little? In part, it's because we are told to. Facebook has more than once overriden its users' privacy preferences, replacing them with new default settings. Facebook then responds to the inevitable public outcry by restoring something that's like the old system, except slightly less private. And it adds a few more lines to an inexplicably complex privacy dashboard.

Even if you read the fine print, human beings are awful at pricing out the net present value of a decision whose consequences are far in the future. No one would take up smoking if the tumors sprouted with the first puff. Most privacy disclosures don't put us in immediate physical or emotional distress either. But given a large population making a large number of disclosures, harm is inevitable. We've all heard the stories about people who've been fired because they set the wrong privacy flag on that post where they blew off on-the-job steam.

The risks increase as we disclose more, something that the design of our social media conditions us to do. When you start out your life in a new social network, you are rewarded with social reinforcement as your old friends pop up and congratulate you on arriving at the party. Subsequent disclosures generate further rewards, but

not always. Some disclosures seem like bombshells to you ("I'm getting a divorce") but produce only virtual cricket chirps from your social network. And yet seemingly insignificant communications ("Does my butt look big in these jeans?") can produce a torrent of responses. Behavioral scientists have a name for this dynamic: "intermittent reinforcement." It's one of the most powerful behavioral training techniques we know about. Give a lab rat a lever that produces a food pellet on demand and he'll only press it when he's hungry. Give him a lever that produces food pellets at random intervals, and he'll keep pressing it forever.

How does society get better at preserving privacy online? As Lawrence Lessig pointed out in his book *Code and Other Laws of Cyberspace*, there are four possible mechanisms: norms, law, code, and markets.

So far, we've been pretty terrible on all counts. Take norms: our primary normative mechanism for improving privacy decisions is a kind of pious finger-wagging, especially directed at kids. "You spend too much time on those Interwebs!" And yet schools and libraries and parents use network spyware to trap every click, status update, and IM from kids, in the name of protecting them from other adults. In other words: your privacy is infinitely valuable, unless we're violating it. (Oh, and if you do anything to get around our network surveillance, you're in deep trouble.)

What about laws? In the United States, there's a legal vogue for something called "Do Not Track": users can instruct their browsers to transmit a tag that says, "Don't collect information on my user." But there's no built-in compliance mechanism—we can't be sure it works unless auditors descend on IT giants' data centers to ensure they aren't cheating. In the EU, they like the idea that you own your data, which means that you have a property interest in the facts of your life and the right to demand that this "property" not be misused. But this approach is flawed, too. If there's one thing the last 15 years of Internet policy fights have taught us, it's that nothing is ever solved by ascribing property-like rights to easily copied information.

The users and the analytics people are in a shooting war, but only the analytics people are armed. There's a business opportunity for a company that supplies arms to the rebels instead of the empire.

There's still room for improvement—and profit—in code. A great deal of Internet-data harvesting is the result of permissive defaults on how our browsers handle cookies, those bits of code used to track us. Right now, there are two ways to browse the Web: turn cookies off altogether and live with the fact that many sites won't work; or turn on all cookies and accept the wholesale extraction of your Internet use habits.

Browser vendors could take a stab at the problem. For a precedent, recall what happened to pop-up ads. When the Web was young, pop-ups were everywhere. They'd appear in tiny windows that re-spawned when you closed them. They ran away from your cursor and auto-played music. Because pop-ups were the only way to command a decent rate from advertisers, the conventional wisdom was that no browser vendor could afford to block pop-ups by default, even though users hated them.

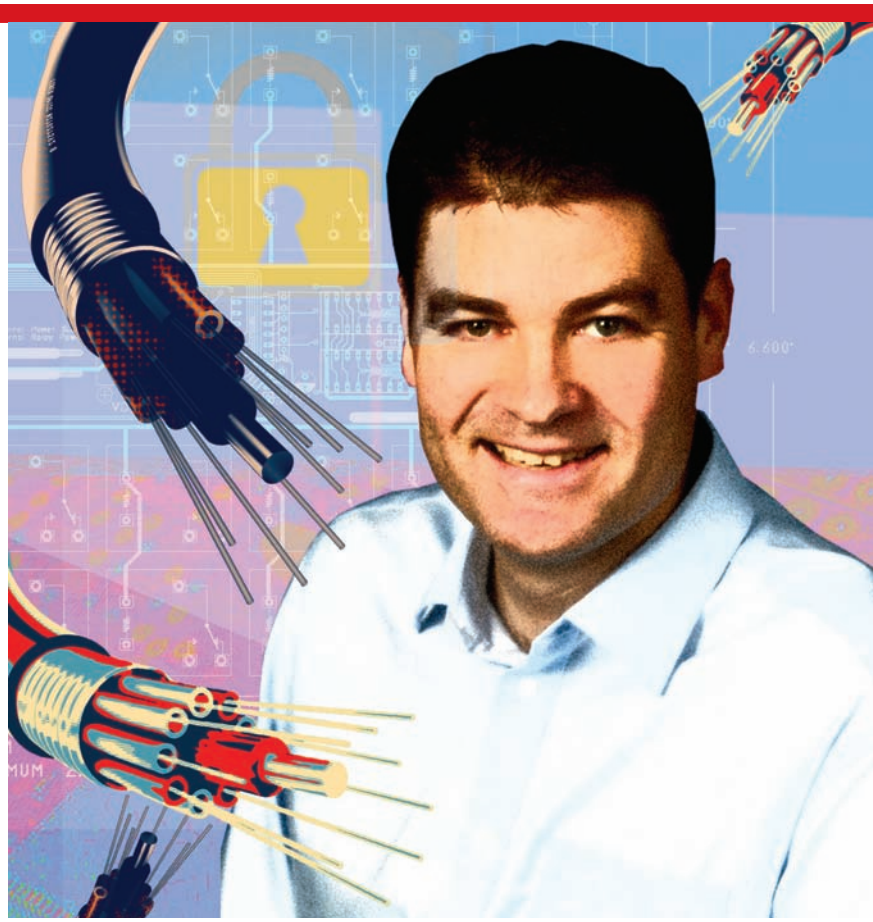
The deadlock was broken by Mozilla, a nonprofit foundation that cared mostly about serving users, not site owners or advertisers. When Mozilla's Firefox turned on pop-up blocking by default, it began to be wildly successful. The other browser vendors had no choice but to follow suit. Today, pop-ups are all but gone.

Cookie managers should come next. Imagine if your browser loaded only cookies that it thought were useful to you, rather than dozens from ad networks you never intended to interact with. Advertisers and media buyers will say the idea can't work. But the truth is that dialing down Internet tracking won't be the end of advertising. Ultimately, it could be a welcome change for those in the analytics and advertising business. Now it seems as if everyone gets to slurp data out of your computer, regardless of whether the service is superior. Once the privacy bargain takes place without coercion, good companies will be able to build services that get more data from their users than bad companies.

For mobile devices, we'd need more sophisticated tools. Today, mobile-app marketplaces present you with take-it-or-leave-it offers. If you want to download that Connect the Dots app to entertain your kids on a long car ride, you must give the app access to your phone number and location. What if mobile OSes were designed to let their users instruct them to lie to apps? "Whenever the Connect the Dots app wants to know where I am, make something up. When it wants my phone number, give it a random one." An experimental module for Cyanogenmod (a free/open version of the Android OS) already does this. It works moderately well but would be better if it were officially supported by Google.

Far from destroying business, letting users control disclosure would create value. Design an app that I willingly give my location to (as I do with the Hailo app for ordering black cabs in London) and you'd be one of the few and proud firms with my permission to access and sell that information. Right now, the users and the analytics people are in a shooting war, but only the analytics people are armed. There's a business opportunity for a company that wants to supply arms to the rebels instead of the empire. BI

Cory Doctorow is a science fiction author, activist, journalist, and co-editor of *Boing Boing*.



PETER HORVATH

LEADERS

Keeping Things Private at Microsoft

The company and its rivals have important differences when it comes to protecting personal information, says its chief privacy officer.

By LEE GOMES

Earlier this year, Microsoft caused a stir by running big newspaper ads charging that its archrival, Google, was trampling on personal privacy by gathering ever more information on users. Some saw the ads as disingenuous: Microsoft uses some similar practices in its own search engine, Bing.

But inside Microsoft, the claim that it is better at privacy is an article of faith. Microsoft's efforts began in the 1990s, when it battled security holes in its Windows operating system. Back then, privacy meant not having your computer infected with a hacker's malware. Today, it means companies don't abuse your personal data. Journalist Lee Gomes spoke with Brendon Lynch, Microsoft's chief privacy officer.

***TR:* Why did Microsoft criticize Google?**

LYNCH: It was recognizing that there is angst in the environment, that there is concern around privacy for a lot of consumers. We feel proud about the way we build privacy features and controls, and we wanted people to know that there was a choice out there.

Bing recently began letting users sign in with Facebook and share search results. Do you handle social media any differently?

People have to opt in to any experience where search results are shared. Also, Facebook requires users to be 13 or older to access its services, whereas Bing's social search features will only surface results for users who are 18 or older.

What did Microsoft learn during the 1990s, when conspiracy theorists accused you of using Windows updates to spy on people?

That really helped us understand the importance of trust. Windows updates keep society protected from online threats. So we wanted to ensure that we had strong privacy controls in Windows Update, so that people would trust it and use it. One of the things we did was to have independent auditors crawl all over what we were doing and then issue a report that assured everyone we were collecting only the data we said we were collecting.

Does "privacy" mean something different to Microsoft than it did 15 years ago?

Security as it relates to data is primarily about the protection of that data, but privacy is something much broader: "what is the correct use of the data?" There was a lot more focus on security in the early days at Microsoft, but we've been investing deeply over the last 10 years to get us ready for this moment when privacy would become much more important. The big privacy challenge of our time will be enabling society to benefit from information-centric innovations while ensuring that personal privacy is protected.

Do devices like the Kinect game controller present new privacy challenges?

There are some privacy sensitivities—it can do voice recognition, it can do facial recognition. Protecting privacy in this case involved making sure that none of this information leaves the Kinect device. It's not storing the information or sharing it with anything else. BI



CASE STUDIES

A Dollar for Your Data

Information about you is free for the taking on the Web. A new crop of entrepreneurs wants you to collect. By JESSICA LEBER

Unless your name is Oprah Winfrey or Warren Buffett, you'd be hard pressed to find anyone to pay $1,000 to hear about your purchasing habits. Anyone who wants this information can glean much of it from your behavior on the Internet anyway. Companies tracking and aggregating our clicks, taps, and swipes are the ones making fortunes. Individuals are not.

But a startup called Personal thinks it can change this. Its starting point is an idea that may seem strange to the Facebook generation: an online network where users control what information advertisers can access.

Personal, based in Washington, D.C., is among a number of startups that want to help people "collect, curate, and derive value" from their own online data, according to the Personal Data Ecosystem Consortium, a group formed in 2010 to encourage such efforts; it lists 30 businesses as members.

Personal cofounder Shane Green believes that many Internet surfers are primed to share more detailed and revealing information than they commonly do today—so long as they stay in control, and possibly earn money from it.

Users of the network, launched last November, are encouraged to upload information of all sorts, trivial (pizza orders) or sensitive (student loan records, medical prescriptions). They place the data in a "vault" and can grant other people or Web programs access to relevant portions. You could enter your home alarm code and share it only with houseguests, or grant a financial advisor access to details about your retirement accounts.

This year, the company plans to add a marketplace where people will be able to sell access to their personal information—for instance, an intention to buy an SUV in the next four weeks. Local car dealers, Green believes, would want to pay for the chance to advertise or offer incentives to such users because the strategy offers higher odds of a payoff than, say, targeting ads through Google. Green says an individual could earn $1,000 a year in this manner; Personal would take a percentage of advertiser fees.

Green started Personal in 2009 and has raised $11 million from investors. He previously founded an online company that helped owners of stadiums and other facilities create maps of buildings or private events like the Super Bowl. His customers wouldn't have allowed him to resell the data, yet that is exactly what individuals do when they simply give away their location and much more. It is a phenomenon Green considers a "fundamental instability" in the marketplace.

Economists, however, have found major problems with the idea of personal-data marketplaces. Individuals struggle to put a value on their data. And within today's market structure, the value can vary dramatically depending on how it's measured, but often information is exchanged for mere pennies, says Alessandro Acquisti, co-director of Carnegie Mellon University's Center for Behavioral Decision Research.

"I would like these services to succeed," Acquisti says. "At least they provide some more transparency. But I fear they may not." It's unclear so far how many users Personal has; the company declined to say. As of now, Green's startup idea appears to have won more attention from analysts and privacy watchdogs than from consumers.

In the end, people will have to see enough benefit from such services to invest time in maintaining an account, which can involve manually entering information such as the numbers associated with bank accounts or warranties. But Green believes there are big productivity benefits to storing one's valuable information in a single location. Users will have access to a personal data search box, and a feature to be introduced soon will let them safely complete online forms with a single click.

Green says the ultimate challenge for private data networks like his will be maintaining security. As with a bank, if you lock a lot of value in a vault, robbers will try to get in. BI

More on Privacy

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The Facebook Fallacy

For all its valuation, the social network is just another ad-supported site. It needs an earthshaking idea.

By MICHAEL WOLFF

Facebook not only is on course to go bust but will take the rest of the ad-supported Web with it.

Given its vast cash reserves and the glacial pace of business reckonings, this assertion will sound exaggerated. But that doesn't mean it isn't true.

At the heart of the Internet business is one of the great business fallacies of our time: that the Web, with all its targeting abilities, can be a more efficient, and hence more profitable, advertising medium than traditional media. Facebook, with its 900 million users, its valuation of around $60 billion (as of early June), and a business derived primarily from fairly traditional online advertising, is now at the heart of the heart of this fallacy.

Facebook ads
www.facebook.com/advertising

The daily and stubborn reality for everybody building businesses on the strength of Web advertising is that the value of digital ads decreases every quarter, a consequence of their simultaneous ineffectiveness and efficiency. The nature of people's behavior on the Web and of how they interact with advertising, as well as the character of those ads themselves and their inability to command attention, has meant a marked decline in advertising's impact.

At the same time, network technology allows advertisers to more precisely locate and assemble audiences outside of branded channels. Instead of having to go to CNN for your audience, a generic CNN-like audience can be assembled outside CNN's walls and without the CNN-brand markup. This has resulted in the now famous and cruelly accurate formulation that $10 of offline advertising becomes $1 online.

I don't know anyone in the ad-supported Web business who isn't engaged in a relentless, demoralizing, no-exit operation to realign costs with falling per-user revenues, or who isn't manically inflating traffic to compensate for ever-lower per-user value.

Facebook has convinced large numbers of otherwise intelligent people that the magic of the medium will reinvent advertising in a heretofore unimaginably profitable way, or that the company will create something new that isn't advertising, which will produce even more wonderful profits. But because its stock has been trading at about 40 times its expected earnings for the next year, these innovations will have to be something like alchemy to make the company worth its sticker price. For comparison, Google has been trading at a forward P/E ratio of around 11. (To gauge how much faith investors have that Google, Facebook, and other Web companies will extract value from their users, see Graphiti, on page 31.)

Facebook currently derives 82 percent of its revenue from advertising. Most of that is the desultory, ticky-tacky display advertising that litters the right side of people's

BRIAN STAUFFER

Facebook profiles. Some is a kind of social marketing: a user chooses to "like" a product, which is supposed to further social relationships with companies. The social network sells its ads by valuing various combinations of the cost of a thousand ad impressions (or CPM) and the cost of a click (CPC). Both forms of ads are more or less coarsely targeted to users on the basis of information they've volunteered to provide to Facebook and the sharing or "liking" of media within Facebook's universe. General Motors recently announced it would no longer buy any kind of Facebook ad.

Facebook's answer to its critics is: Pay no attention to the carping. Sure, grunt-like advertising produces the overwhelming portion of our $4 billion in revenues, and yes, on a per-user basis, these revenues are in decline. But this stuff is really not what we have in mind. Just wait.

It's quite a juxtaposition of realities. On the one hand, Facebook is under the same relentless downward pressure as other Web-based media. The company's revenue amounts to a pitiful $5 per customer per year, which puts it ahead of the *Huffington Post* but somewhat behind the *New York Times'* digital business. (Here's the heartbreaking truth about the difference between new media and old: even in the *New York Times'* declining traditional business, a subscriber is still worth more than $1,000 a year.) Facebook's business grows only on the unsustainable basis that it can add new customers at a faster rate than the price of advertising declines. It is peddling as fast as it can. And the present scenario gets much worse as people increasingly interact with the social service on mobile devices, because on a small screen it is vastly harder to sell ads and monetize users.

On the other hand, Facebook is, everyone has come to agree, profoundly *different* from the Web. First of all, it exerts a new level of hegemonic control over users' experiences. And it has its vast scale: 900 million, soon a billion, eventually two billion people. (One of the problems with the logic of constant growth at this scale and speed is that eventually Facebook will run out of humans with computers or smart phones.) And then it is social. Facebook has, in some yet-to-be-defined way, redefined *something*. Relationships? Media? Communications? Communities? Something big, anyway.

The subtext—an overt subtext—of the popular account of Facebook is that the network has a proprietary claim to and special insight into social behavior. For enterprises and advertising agencies, it is therefore the bridge to new modes of human connection.

The sweeping, basic, transformative, and simple way to connect buyer to seller and get out of the way eludes Facebook. It has to sell its audience like every humper on Madison Avenue.

Expressed so baldly, this account is hardly different from what was claimed for the companies most aggressively boosted during the dot-com boom. But there is, in fact, *one* company that created and harnessed a transformation in behavior and business: Google. Facebook could be, or in many people's eyes should be, something similar. Lost in such analysis is the failure to describe the application that will drive revenues.

Google is an incredibly efficient system for placing ads. In a disintermediated advertising market, the company has turned itself into the last and ultimate middleman. On its own site, it controls the space where a buyer searches for a thing and where a seller hawks that thing (AdWords, its keywords advertising network). Google is also the cheapest, most efficient way to place ads anywhere else on the Web (through the AdSense network). It's not a media company in any traditional sense; it's a facilitator. It can eliminate the whole laborious, numbing process of selling advertising space: if a marketer wants to place an ad (that is, if it is already convinced it must advertise), the company calls Mr. Google.

And that's Facebook's hope, too: it wants to be a facilitator, the inevitable conduit at the center of the world's commerce.

Facebook has the scale, the platform, and the brand to be the new Google. It lacks only the big idea. Right now, it doesn't actually know how to embed its usefulness into world commerce (or even, really, what its usefulness *is*).

But Google didn't have the big idea at its founding, either. The search engine borrowed the concept of AdWords from Yahoo's Overture network (a lawsuit for patent infringement and a settlement followed). Now Google has all the money in the world to buy or license the ideas that could make its platform and brand pay off.

What might Facebook's big idea look like? Well, it does have all this data. The company knows so much about so many people that its executives are sure the knowledge must have value (see this month's cover story, "What Facebook Knows," on page 42).

If you're inside the Facebook galaxy—a constellation that includes an ever-expanding cloud of associated ventures—there is endless chatter about a near-utopian new medium for marketing. Round and round goes the conversation: "If we just ... if only ... when we will ..." If, for instance, frequent-flier programs and travel destinations actually knew when you were thinking about planning a trip ... If a marketer could identify the person who has the most influence on you ... If an advertiser could introduce you to someone who would relay the advertising message ... Get it? No ads, just friends! My God!

But so far the sweeping, basic, transformative, and simple way to connect buyer to seller and get out of the way eludes Facebook.

So the social network is left in the same position as all other media companies. Instead of being inevitable and unavoidable, it has to sell its audience like every humper on Madison Avenue.

But that's what Facebook is doing: selling individual ads. If you consider only its revenue, it's an ad-sales business, not a technology company. To meet expectations—the expectations that took it public at $100 billion—it has to sell at near hyperspeed.

The growth of its user base and its ever-swelling page views mean an almost infinite inventory to sell. But the expanding supply, together with equivocal demand, results in ever-lowering prices. The math is sickeningly inevitable. Absent that earthshaking idea, Facebook will look forward to slowing or declining growth in a tapped-out market, and ever-falling ad rates, both on the Web and (especially) in mobile applications. Facebook isn't Google; it's Yahoo or AOL.

Oh, yes ... in its Herculean efforts to maintain its overall growth, Facebook will force the rest of the ad-driven Web to lower its prices, too. The low-level panic the owners of every mass-traffic website feel about the ever-downward movement of their CPM is turning to dread. Last quarter, some big sites observed as much as a 25 percent decrease, following Facebook's own attempt to book more revenue.

You see where this is going. As Facebook gluts an already glutted market, the fallacy of the Web as a profitable ad medium will become hard to ignore. The crash will come. And Facebook—that putative transformer of worlds, which is, in reality, only an ad-driven site—will fall with everybody else. tr

Michael Wolff, a contributing editor to *Vanity Fair*, writes a column on media for the *Guardian*, founded Newser, and was, until October of last year, the editor of *Adweek*.



CORBETT LEE/FOUNDATION FIGHTING BLINDNESS/AP

You Will Want Google Goggles

I thought that glasses with "augmented reality" would be hopelessly dorky and could never go mainstream—until I saw the technology in action.

By FARHAD MANJOO

At first glance, Thad Starner does not look out of place at Google. A pioneering researcher in the field of wearable computing, Starner is a big, charming man with unruly hair. But everyone who meets him does a double take, because mounted over the left lens of his eyeglasses is a small rectangle. It looks like a car's side-view mirror made for a human face. The device is actually a minuscule computer monitor aimed at Starner's eye; he sees its display—pictures, e-mails, anything—superimposed on top of the world, Terminator-style.

Google's Project Glass
https://plus.google.com/111626127367496192147/posts

Starner's heads-up display is his own system, not a prototype of Project Glass, Google's recently announced effort to build augmented-reality goggles. In April, Google X, the company's special-projects lab, posted a video in which an imaginary user meanders around New York City while maps, text messages, and calendar remind-

Google cofounder Sergey Brin wore a Project Glass prototype at a charity function in San Francisco in April.

ers pop up in front of his eye—a digital wonderland overlaid on the analog world. Google says the project is still in its early phases; Google employees have been testing the technology in public, but the company has declined to show prototypes to most journalists, including myself.

Instead, Google let me speak to Starner, a technical lead for the project, who is one of the world's leading experts on what it's like to live a cyborg's life. He has been wearing various kinds of augmented-reality goggles full time since the early 1990s, which once meant he walked around with video displays that obscured much of his face and required seven pounds of batteries. Even in computer science circles, then, Starner has long been an oddity. I went to Google headquarters not only to find out how he gets by in the world but also to challenge him. Project Glass—and the whole idea of machines that directly augment your senses—seemed to me to be a nerd's fantasy, not a potential mainstream technology.

But as soon as Starner walked into the colorful Google conference room where we met, I began to question my skepticism. I'd come to the meeting laden with gadgets—I'd compiled my questions on an iPad, I was recording audio using a digital smart pen, and in my pocket my phone buzzed with updates. As we chatted, my attention wandered from device to device in the distracted dance of a tech-addled madman.

Starner, meanwhile, was the picture of concentration. His tiny display is connected to a computer he carries in a messenger bag, a machine he controls with a small, one-handed keyboard that he's always gripping in his left hand. He owns an Android phone, too, but he says he never uses it other than for calls (though it would be possible to route calls through his eyeglass system). The spectacles take the place of his desktop computer, his mobile computer, and his all-knowing digital assistant. For all its utility, though, Starner's machine is less distracting than any other computer I've ever seen. This was a revelation. Here was a guy *wearing a computer*, but because he could use it without becoming lost in it—as we all do when we consult our many devices—he appeared less in thrall to the digital world than you and I are every day. "One of the key points here," Starner says, "is that we're trying to make mobile systems that help the user pay *more* attention to the real world as opposed to retreating from it."

By the end of my meeting with Starner, I decided that if Google manages to pull off anything like the machine he uses, wearable computers seem certain to conquer the world. It simply will be better to have a machine that's hooked onto your body than one that responds to it relatively slowly and clumsily.

I understand that this might not seem plausible now. When Google unveiled Project Glass, many people shared my early take, criticizing the plan as just too geeky for the masses. But while it will take some time to get used to interactive goggles as a mainstream necessity, we have already gotten used to wearable electronics such as headphones, Bluetooth headsets, and health and sleep monitoring devices. And even though you don't exactly wear your smart phone, it derives its utility from its immediate proximity to your body.

In fact, wearable computers could end up being a fashion statement. They actually fit into a larger history of functional wearable objects—think of glasses, monocles, wristwatches, and whistles. "There's a lot of things we wear today that are just decorative, just jewelry," says Travis Bogard, vice president of product management and strategy at Jawbone, which makes a line of fashion-conscious Bluetooth headsets. "When we talk about this new stuff, we think about it as 'functional jewelry.'" The trick for makers of wearable machines, Bogard explains, is to add utility to jewelry without negatively affecting aesthetics.

This wasn't possible 20 years ago, when the technology behind Starner's cyborg life

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was ridiculously awkward. But Starner points out that since he first began wearing his goggles, wearable computing has followed the same path as all digital technology—devices keep getter smaller and better, and as they do, they become ever more difficult to resist. "Back in 1993, the question I would always get was, 'Why would I want a mobile computer?'" he says. "Then the Newton came out and people were still like, 'Why do I want a mobile computer?' But then the Palm Pilot came out, and then when MP3 players and smart phones came out, people started saying, 'Hey, there's something really useful here.'" Today, Starner's device is as small as a Bluetooth headset, and as researchers figure out ways to miniaturize displays—or even embed them into glasses and contact lenses—they'll get still less obtrusive.

At the moment, the biggest stumbling block may be the input device—Starner's miniature keyboard requires a learning curve that many consumers would find daunting, and keeping a trackpad in your pocket might seem a little creepy. The best input system eventually could be your voice, though it could take a few years to perfect that technology. Still, Starner says, the wearable future is coming into focus. "It's only been recently that these on-body devices have enough power, the networks are good enough, and the prices have gone down enough that it's actually capturing people's imagination," Starner says. "This display I'm wearing costs $3,000—that's not reasonable for most people. But I think you're going to see it happen real soon."

One criticism of Google's demo video of Project Glass is that it paints a picture of a guy lost in his own digital cocoon. But Starner argues that a heads-up display will actually tether you more firmly to real-life social interactions. He says the video's augmented-reality visualizations—images that are tied to real-world sights, like direction bubbles that pop up on the sidewalk, showing you how to get to your friend's house—are all meant to be relevant to what you're doing at any given point and thus won't seem like distracting interruptions.

Much of what I think you'll use goggles for will be the sort of quotidian stuff you do on your smart phone all the time—look up your next appointment on your calendar, check to see whether that last text was important, quickly fire up Shazam to learn the title of a song you heard on the radio. So why not just keep your smart phone? Because the goggles promise speed and invisibility. Imagine that one afternoon at work, you meet your boss in the hall and he asks you how your weekly sales numbers are looking. The truth is, you haven't checked your sales numbers in a few days. You could easily look up the info on your phone, but how obvious would that be? A socially aware heads-up display could someday solve this problem. At Starner's computer science lab at the Georgia Institute of Technology, grad students built a wearable display system that listens for "dual-purpose speech" in conversation—speech that seems natural to humans but is actually meant as a cue to the machine. For instance, when your boss asks you about your sales numbers, you might repeat, "This week's sales numbers?" Your goggles—with Siri-like prowess—would instantly look up the info and present it to you in your display.

One criticism of Google's demo video of Project Glass is that it paints a picture of a guy lost in his own digital cocoon. But Starner argues that a heads-up display will actually tether you more firmly to real-life social interactions.

You could argue that the glasses would open up all kinds of problems: would people be concerned that you were constantly recording them? And what about the potential for deeper distraction—goofing off by watching YouTube during a meeting, say? But Starner counters that most of these problems exist today. Your cell phone can record video and audio of everything around you, and your iPad is an ever-present invitation to goof off. Starner says we'll create social and design norms for digital goggles the way we have with all new technologies. For instance, you'll probably need to do something obvious—like put your hand to your frames—to take a photo, and perhaps a light will come on to signal that you're recording or that you're watching a video. It seems likely that once we get over the initial shock, goggles could go far in mitigating many of the social annoyances that other gadgets have caused.

I know this because during my hour-long conversation with Starner, he was constantly pulling up notes and conducting Web searches on his glasses, but I didn't notice anything amiss. To an outside observer, he would have seemed far less distracted than I was. "One of the coolest things is that this makes me more socially graceful," he says.

I got to see this firsthand when Starner let me try on his glasses. It took my eye a few seconds to adjust to the display, but after that, things began to look clearer. I could see the room around me, except now, hovering off to the side, was a computer screen. Suddenly I noticed something on the screen: Starner had left open some notes that a Google public-relations rep had sent him. The notes were about me and what Starner should and should not say during the interview, including "Try to steer the conversation away from the specifics of Project Glass." In other words, Starner was being coached, invisibly, right there in his glasses. And you know what? He'd totally won me over.

Farhad Manjoo is the technology columnist at *Slate* and contributes regularly to *Fast Company* and the *New York Times*. He is the author of *True Enough: Learning to Live in a Post-Fact Society*.

Why Publishers Don't Like Apps

The future of media on mobile devices isn't with applications but with the Web.

By JASON PONTIN

By the time Apple released the iPad in April of 2010, only four months after Steve Jobs first announced his "magical and revolutionary" new machines, traditional publishers were gripped by a collective delusion. They had convinced themselves that tablet computers and smart phones would allow them to unwind their unhappy histories with the Internet.

For publishers whose businesses had evolved during the long day of print newspapers and magazines, the expansion of the Internet was terribly disorienting. The Web taught readers that they might read stories whenever they liked without charge, and it offered companies more efficient ways to advertise; both parties spent less.

Smart phones and tablets seemed to promise a return to simpler days. It was true that digital replicas of print newspapers and magazines (most often read inside Web browsers) had never been very popular, but publishers reasoned that reading replicas on desktop computers and laptops was an unpleasant experience. The forms of the new smart devices were *a little* like those of magazines or newspapers. Couldn't publishers delight readers by delivering something similar to existing digital replicas but suitably enhanced with interactive features? They told themselves that the new digital replicas would be better than their Web-bound kin because they would run in "native" applications on mobile operating systems like Apple's iOS, and thus would possess the dazzling functions of true software.

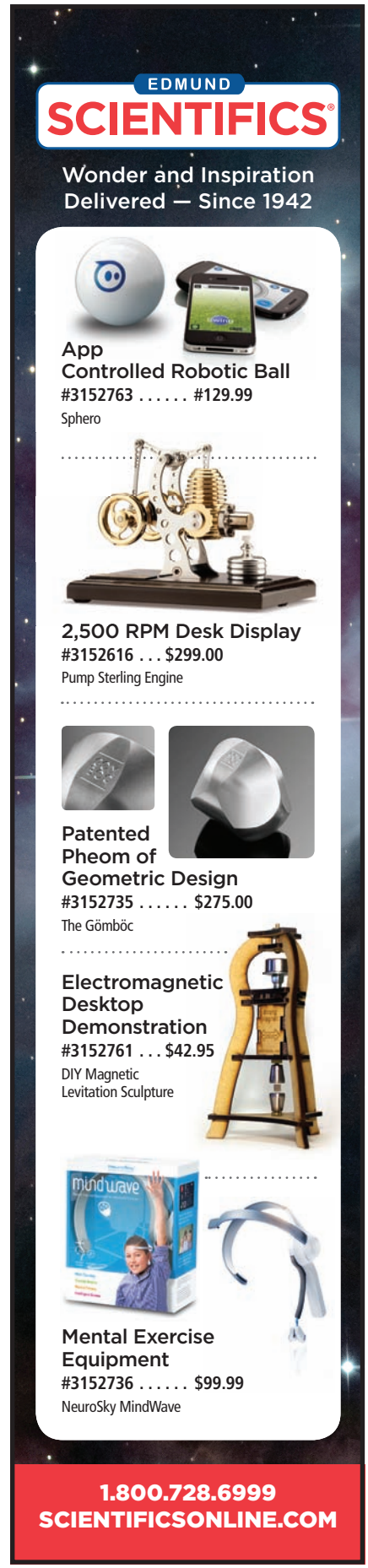
For traditional publishers, the scheme was alluring. Because they were once again delivering a discrete product, analogous to a newspaper or magazine, they could charge readers for single-copy sales and subscriptions, reëducating audiences that journalism was something valuable for which they must pay. Software vendors like Adobe promised that editorial created with their print-oriented copy-management systems could be "seamlessly" transferred to the apps. And as for software development ... well, how hard was that? Most publishers had Web-development departments: let the nerds build the apps.

***Technology Review* iPad app**
version 2.0

The Daily
iPad-only newspaper

Financial Times
HTML5 website
www.ft.com

Publishers also expected to revive the old print advertising economy. The Audit Bureau of Circulations (ABC), the industry organization that audits circulation and audience information for magazines and newspapers in North America, said the replicas inside apps would count toward "rate base," the measure of publications' total circulation, which includes subscription and newsstand sales. Rate base had been the metric for setting advertising rates in publishing before the emergence of online banner and keyword advertising, where electronic arcana like click-throughs and ad impressions are the accepted currencies. Apps would return media to its proper, historical structure: publishers could sell digital versions of the same ads that appeared in their print publications (perhaps with a markup if the ad had interactive elements), valued with the old measurement of rate base.



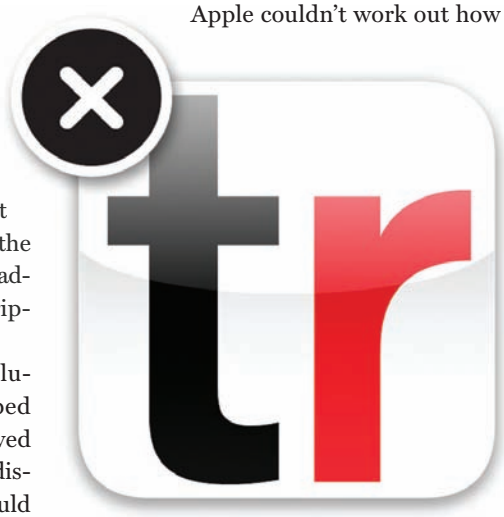
People lost their heads. One symptom of the industry's euphoria was a brief-lived literary genre, the announcement of the iPad edition. In late 2010, the *New Yorker*'s editors gushed: "This latest technology ... provides the most material at the most advanced stage of digital speed and capacity. It has everything that is in the print edition and more: extra cartoons, extra photographs, videos, audio of writers and poets reading their work. This week's inaugural tablet issue features an animated version of David Hockney's cover, which he drew on an iPad." Giddiest of all was the chief executive of News Corp., Rupert Murdoch: he lavished $30 million on the launch of *The Daily,* an experimental iPad-only newspaper with a $39.99 subscription price.

Unpacked in this fashion, the delusion is clear enough, but I succumbed myself—at least a little. I never believed that apps would unwind my industry's disruption, but I felt that some readers would want a beautifully designed digital replica of *Technology Review* on their mobile devices, and I bet that our developers could create a better mobile experience within applications. I liked the idea of bundling inside an app all the editorial we produced, including the daily news and video we post to TechnologyReview.com. So we created iOS and Google Android apps that were free to download: anyone could read our daily news or watch our videos without charge, but they had to pay to see digital replicas of the magazine.

We launched the platforms in January of 2011. Complimenting myself on my conservatism, I budgeted less than $125,000 in revenue in the first year. That meant fewer than 5,000 subscriptions and a handful of single-issue sales. Easy, I thought. What could go wrong?

Like almost all publishers, I was badly disappointed. What went wrong? Everything.

Apple demanded a 30 percent vigorish on all single-copy sales through its iTunes store. While publishers were accustomed to handing over as much as 50 percent to newsstand distributors, the depth of the cut smarted because it was unexpected; many publishers responded by not selling single copies in Apple's store. Then, for a year after the launch of the iPad, Apple couldn't work out how



to sell subscriptions in a way that satisfied ABC, which requires publishers to record "fulfillment" information about subscribers. When Apple finally solved the problem of transferring fulfillment data to publishers, it again claimed its 30 percent share. That hurt more than the vig on single-issue sales: publishers have always hated sharing subscription revenues with third parties, a business they associate with shady resellers who traffic in notoriously disloyal readers. Starting in June of last year, Apple did allow publishers to directly fulfill subscriptions through their own Web pages (a handful of publishers, including *Technology Review,* had enjoyed the privilege earlier), but the mechanism couldn't match iTunes for ease of use. Google was more reasonable in its terms, but Android never emerged as a significant alternative to the iPad: today, most tablet computers are still Apple machines.

There were other difficulties. It turned out that it wasn't at all simple to adapt print publications to apps. A large part of the problem was the ratio of the tablets: they possessed both a "portrait" (vertical) and "landscape" (horizontal) view, depending on how the user held the device. Then, too, the screens of smart phones were much smaller than those of tablets. Absurdly, many publishers ended up producing *six* different versions of an editorial product: a print publication, a conventional digital replica for Web browsers and proprietary software,

The real problem with apps was that when people read on electronic media, they expect the stories to possess the *linky-ness* of the Web—but the stories in apps didn't really link.

a digital replica for landscape viewing on tablets, something that was not quite a digital replica for portrait viewing on tablets, a kind of hack for smart phones, and ordinary HTML pages for their websites.

Software development of apps was much harder than publishers had anticipated, because they had hired Web developers who knew technologies like HTML, CSS, and JavaScript. Publishers were astonished to learn that iPad apps were in fact real, if small, applications, written mostly in a language called Objective C, which no one in their Web-dev departments knew. Publishers responded by outsourcing app development, which was expensive, time-consuming, and unbudgeted.

But the real problem with apps was more profound. When people read news and features on electronic media, they expect the stories to possess the *linky-ness* of the Web—but stories in apps didn't really link. The apps were, in the jargon of information technology, "walled gardens," and although sometimes beautiful,

TECHNOLOGY REVIEW

they were small and stifling. For readers, none of the novelty or prettiness of apps overcame the weirdness and frustration of reading digital media closed off from other digital media.

The Daily's fortunes were not atypical: the publication has found only 100,000 subscribers, well short of the half-million Rupert Murdoch said would be necessary to make it a viable business. The gloom was general. With few subscribers and single-copy buyers, there were no audiences to sell to advertisers, and therefore no revenues to offset the incremental costs of app development. Most publishers soured on apps.

The most commonly cited exception to the general bitterness is Condé Nast, which saw its digital sales increase by 268 percent last year after Apple introduced an iPad app called Newsstand. Still, even 268 percent growth may not be saying much in total numbers: digital is a small business for Condé Nast. *Wired* magazine, among the most digital of Condé Nast's titles, had 33,237 digital-only subscriptions last year, representing just 4.1 percent of a total circulation of 812,434, and 7,004 digital single-copy sales, which is 0.8 percent of paid circulation, according to ABC. (*Wired* spins the numbers differently, claiming a digital circulation of 108,622; but that sum includes the 68,380 print subscribers who activated free digital access.) Similarly, the *New Yorker*, another Condé Nast publication, last year had only 26,880 digital-only subscribers among its million subscribers.

Today, most owners of mobile devices read news and features on publishers' websites, which have often been coded to adapt themselves to smaller screens. Or, if they do use apps, the apps are glorified RSS readers, such as Google Reader, Flipboard, and the apps of newspapers like the *Guardian*, which grab editorial from the publisher's site. A recent Nielsen study reported that while 33 percent of tablet and smart-phone users had downloaded news apps in the previous 30 days, just 19 percent of users had paid for any of them. Apps are good for plenty of things: you can use them to translate street signs in a foreign city, or discover the cheapest bulk source of floor wax, or, if you're carefree and so inclined, hook up with willing partners. But the paid, expensively developed publisher's app, with its extravagantly produced digital replica, is increasingly uncommon.

The recent history of the *Financial Times* is instructive. Last June, the company pulled its iPad and iPhone app from iTunes and launched a new version of its website written in HTML5, which can optimize a site for any device and provide features and functions that are app-like. For a few months, the *FT* continued to support the iPad and iPhone app, but on May 1, the paper chose to kill it altogether.

And *Technology Review*? We sold 353 subscriptions through the iPad. We never discovered how to avoid the necessity of designing both landscape and portrait versions of the magazine for the app. We wasted $124,000 on outsourced software development, a sum that does not begin to capture our allocation of internal resources. We fought among ourselves, and people left the company. There was untold expense of spirit. I hated every moment of our experiment with apps, because it tried to impose something closed, old, and print-like on something open, new, and digital.

Last fall, in version 3.0 of our apps, we moved the editorial content, including the magazine, into simple RSS feeds in "rivers of news." We dumped the digital replica altogether. Now we're redesigning TechnologyReview.com, which we have made free to use, and we'll follow the *Financial Times* in using HTML5, so that our Web pages will look great on a laptop or desktop, tablet, or smart phone. Then we'll kill our apps, too. Now we just need to discover how to make the Web pay. tr

Jason Pontin is the editor in chief and publisher of *Technology Review*.

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Lithium-Ion Battery

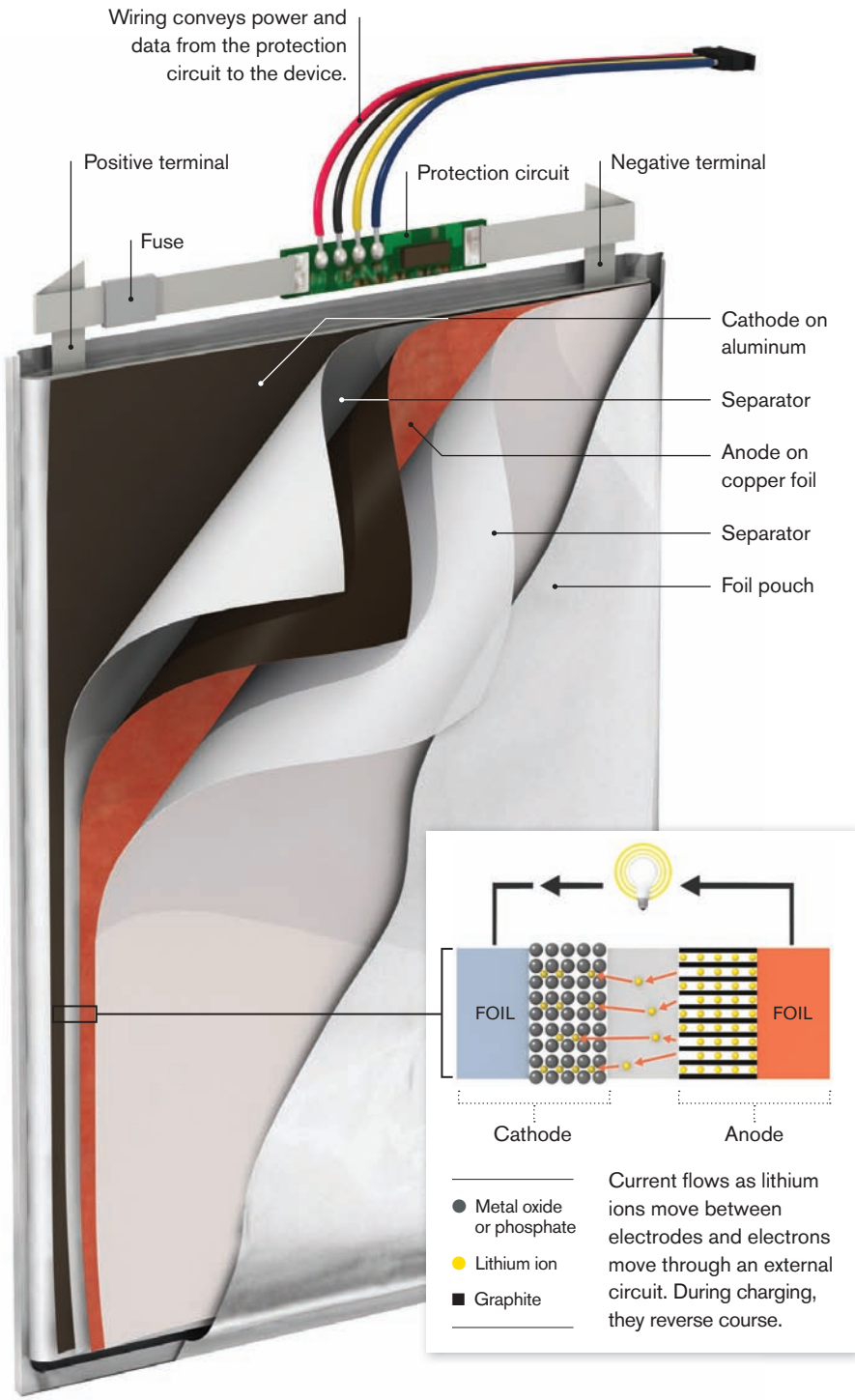
Inside the power source for portable electronics and electric vehicles

By KEVIN BULLIS

Lithium-ion batteries, because they're lightweight and compact, have enabled smart phones to get slimmer and electric vehicles more practical. Like all batteries, they work by means of chemical reactions that send electrons and ions from one electrode to another. Lithium-ion batteries, like the e-book battery shown here, require safety measures such as a fuse to prevent them from catching fire. Battery configurations vary, but generally the electrodes must be thin enough to allow lithium ions to move readily in and out of them. Electrode materials are deposited on foil that collects electrons and conveys them out of the battery. The electrodes don't store much energy by area, so long strips of them are folded or rolled up to boost the battery's capacity.

Illustration by John MacNeill

Technical advisors: Jonathon Harding and Seung Woo Lee





A typical e-book battery (right) contains a copper foil coated with black graphite, the negative electrode material (middle). Peeling back more layers reveals the dark-gray positive electrode and the white electrolyte-soaked separator material (far right), which provides a path for lithium ions to travel between the electrodes but blocks electrons.

PHOTOS: TECHNOLOGY REVIEW

demo

Building an Organ on a Chip

Microscale devices that mimic human organs could provide a much more realistic environment for drug discovery.

By SUSAN YOUNG

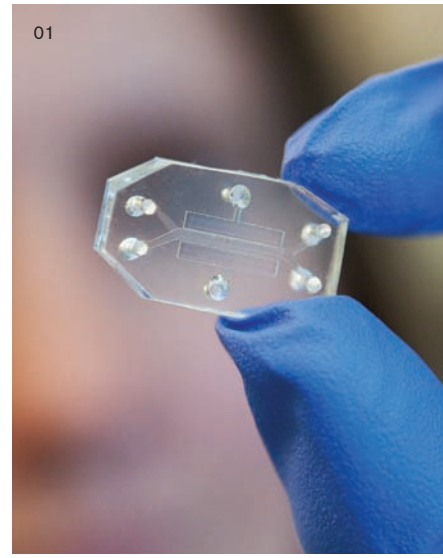


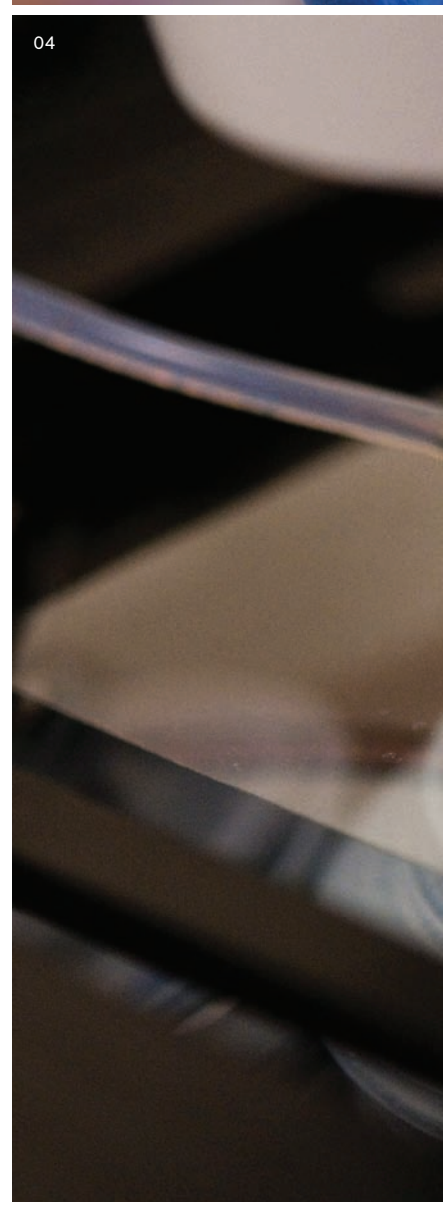
The way pharmaceutical companies test drugs is broken, and Donald Ingber has an idea for how to fix it.

Scientists typically test potential pharmaceuticals on animals, but more often than not, "the predictions from animals fail when a compound is tested in humans," says Ingber, director of Harvard University's Wyss Institute. Performing initial tests on people, of course, is too dangerous. "Our proposed solution is to do studies with human cells," he says, "but not just cells in a dish—cells that exhibit organlike structures and functions."

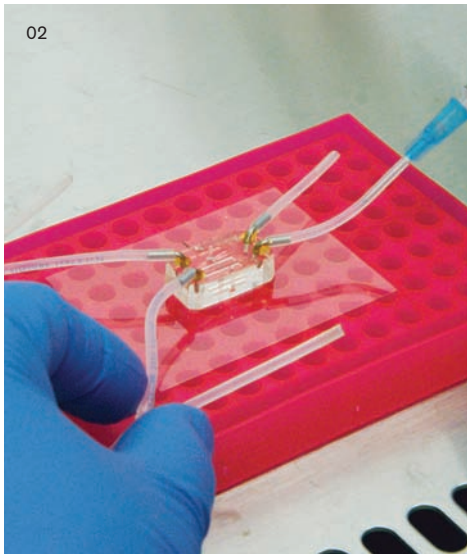
To achieve this, Ingber and his team are developing a menagerie of microscale devices that replicate the structures and environments of actual human organs more closely than a simple culture dish.

The Wyss Institute's first organ was a breathing lung on a microchip. The transparent, thumb-size device is made of cell-friendly materials and serves as a platform for growing human lung cells. Tiny channels cut through the device. Air and liquid flow through the central channels, where the lung cells are grown, and because the device is flexible, scientists can apply vacuum pres-


01


04

PHOTOGRAPHS BY JOSHUA TOUSTER

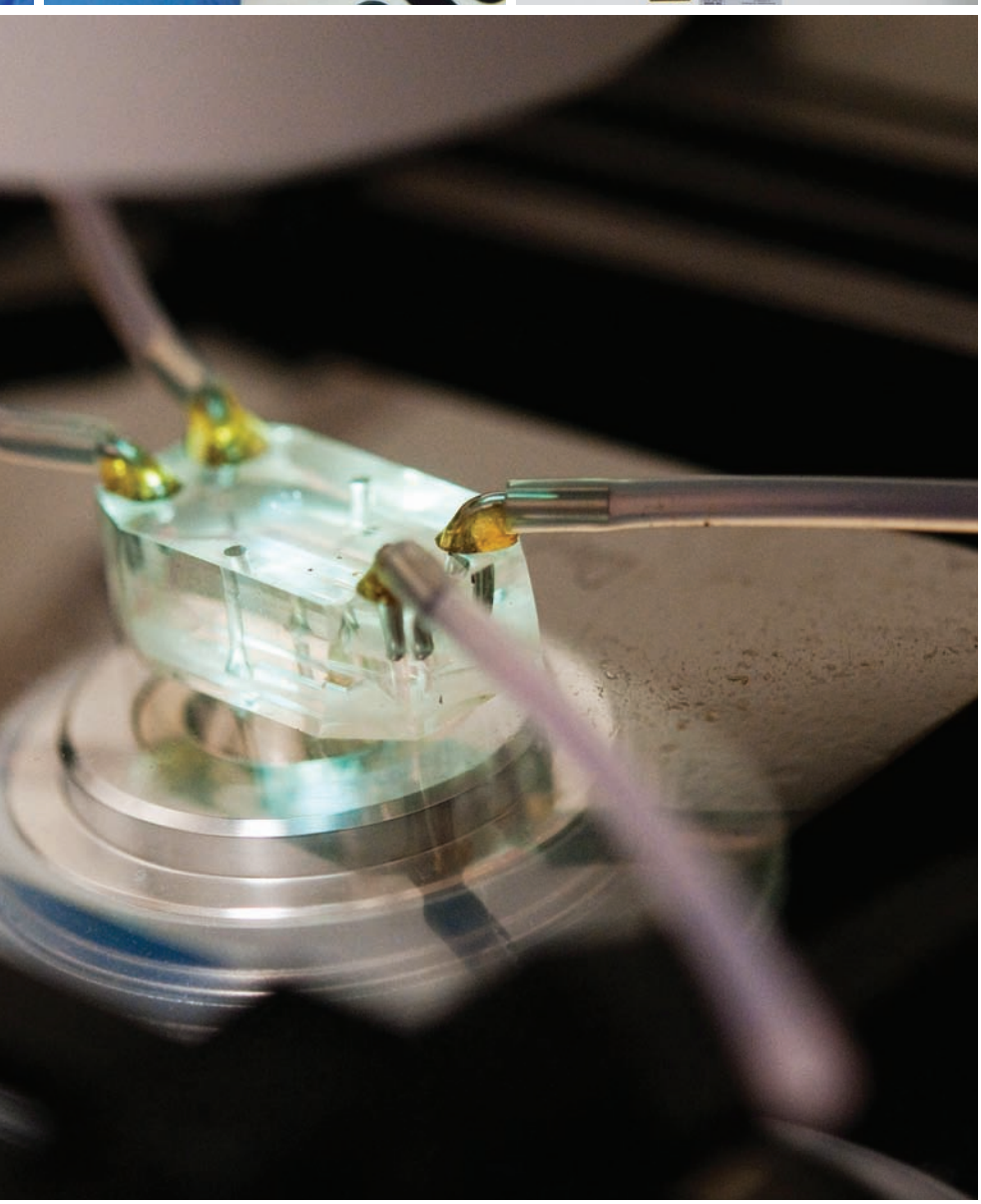




01 The “gut on a chip” shown here is the Wyss Institute’s latest device for growing cells in an organlike environment. This chip contains two microfluidic channels separated by a porous membrane on which intestinal cells can grow.

02 A scientist seeds a new gut chip with cells. Tubing connects a syringe filled with cultured cells, which flow into the chip’s microfluidic channels and attach to the central membrane. There they form a layer similar to the intestinal lining.

03 The cells are then grown in an incubator while a pump (red box) supplies a constant flow of fluids to mimic conditions in the human gut. Researchers could expose the cells to drugs at this stage.





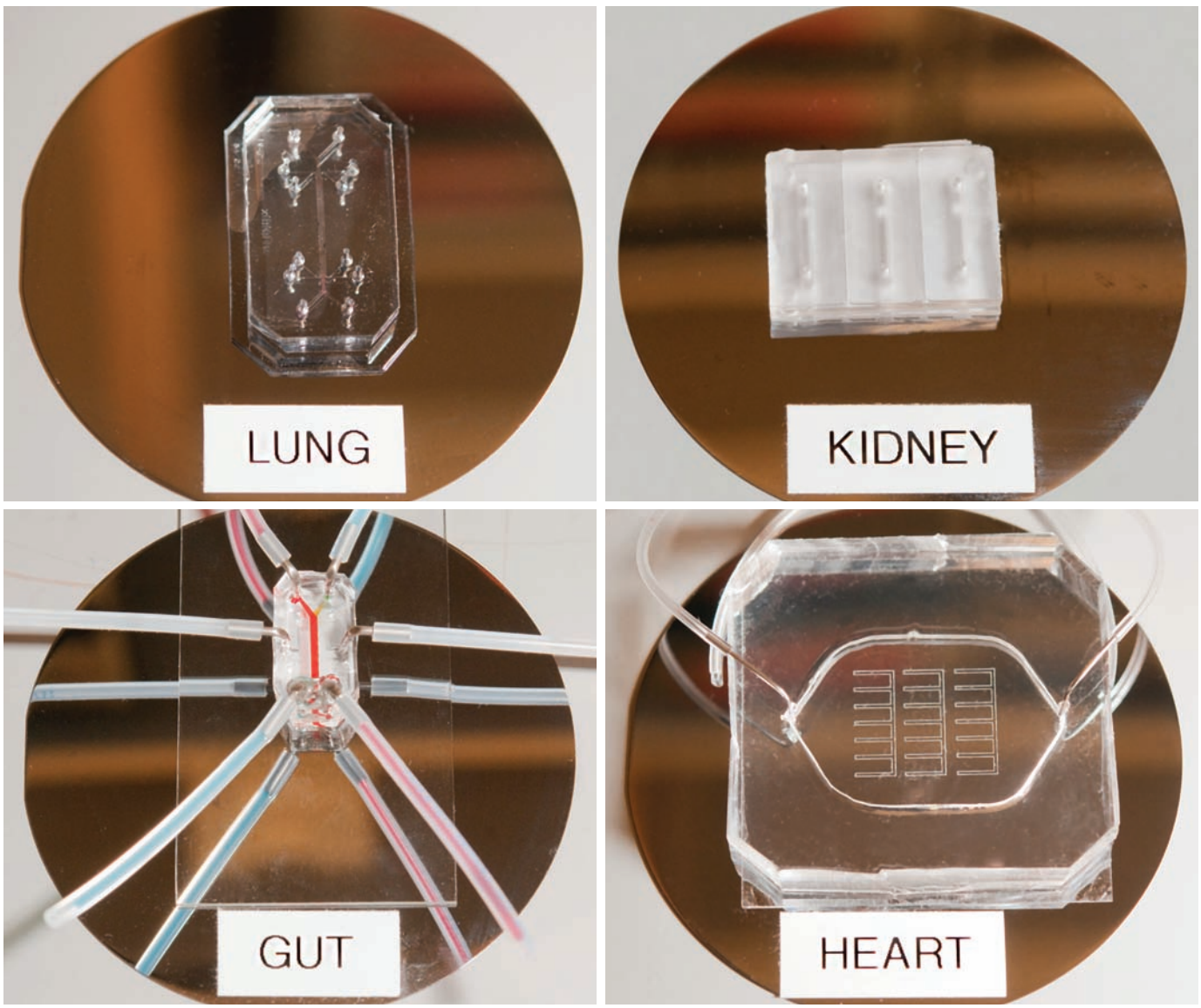


04 After a few days of growth, the cells are ready to be examined. A researcher moves the chip to a microscope and hooks up tubing that will keep nutrients flowing across the cells.

05 While the chip is under the microscope, syringes driven by pumps (not shown) provide sufficient force to move fluids through it.

06 Wyss Institute postdoctoral fellow Hyun Jung Kim, who developed the gut chip, looks at the cells through the microscope. The cells are also displayed on the computer screen on the right.

Wyss researchers have mimicked various organs and hope soon to connect them for more comprehensive drug testing.

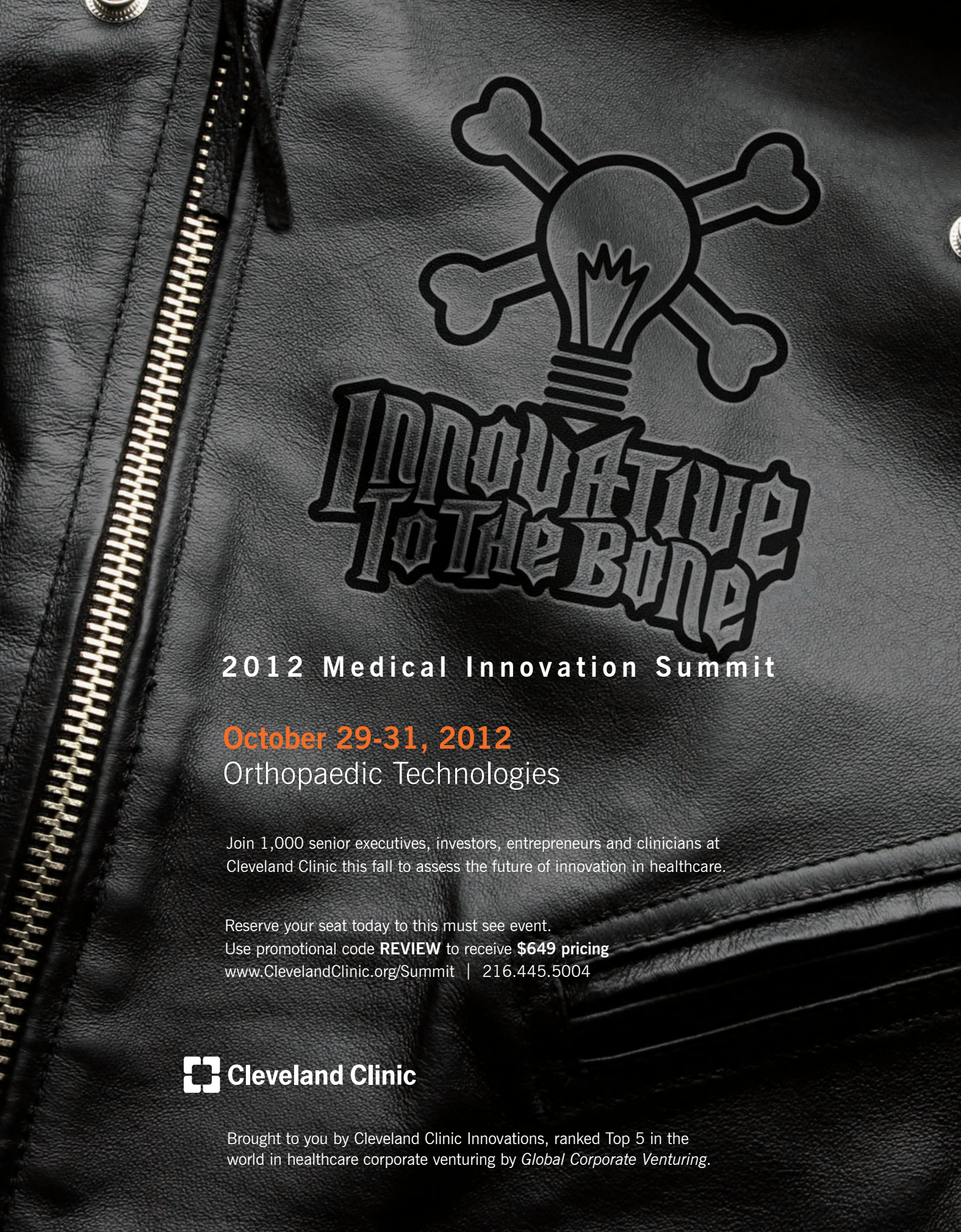


sure to the side channels so that the central channels expand and contract—much like human lungs. The team has shown that such mechanical forces affect the behavior of the cells. In the case of the lung cells, the mechanical breathing helps them absorb particles flowing in the air chamber.

More recently, the institute has developed a human gut on a microchip. The central channel of the device, which is lined with human cells, can be subjected to wavelike motions that mimic the movement of the intestines during digestion. In the chip, the cells form fingerlike structures known as villi that are important for absorption of nutrients and other compounds. These structures do not form when cells are grown in a dish, suggesting that the cells feel more at home in the device. Scientists can also grow common intestinal bacteria along with the gut cells in the channel. In a culture dish, the bacteria usually overtake the human cells, says Ingber; "now we can study much more complex interactions."

Individually, each organlike chip gives researchers a chance to study human cells in a more natural environment and to test how they respond to drugs and toxins. But Ingber is working toward a grander vision in which several of the chips are linked together. By connecting the microfluidic versions of a heart, lung, gut, kidney, and more, Ingber and his coworkers believe, they will be able to better study how the body processes and responds to various compounds.

One project under way with Wyss faculty member Kevin Kit Parker is to test inhaled drugs for negative effects on the heart—a long-standing problem in drug discovery. "Cardiac toxicity is actually the biggest cause of failure of drugs, regardless of what they target," says Ingber. tr



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from the labs

MATERIALS

Oil Spill Sponge

A unique nanotube material may beat the best sorbents on the market

SOURCE: "COVALENTLY BONDED THREE-DIMENSIONAL CARBON NANOTUBE SOLIDS VIA BORON INDUCED NANOJUNCTIONS"

Pulickel M. Ajayan et al.

Nature Scientific Reports, published online April 13, 2012

RESULTS: Adding a small amount of boron to carbon nanotubes helped bond them together to form a strong, three-dimensional network. The result was a resilient, ultralight sponge that could soak up more than 100 times its weight in oil and repel water.

WHY IT MATTERS: Scientists have had trouble bonding nanotubes together so that they can form large structures, but the new technique provides a way to do that. The first application could be making sorbents for cleaning up oil spills. Initial measurements suggest that the sponge can absorb more than three times as much oil or solvent as the best sorbents on the market but does not take up water, unlike some used now.

The sponge could be reused after squeezing out the oil or burning it off. Among other potentially useful qualities, it has good conductivity, can easily be magnetized, and is one of the lowest-density solids in existence. Its properties might make it useful for other applications, such as high-performance battery electrodes or scaffolding for growing bone tissue.

METHODS: Researchers formed nanotubes by creating a mist made of microdroplets of chemical ingredients and then heating it in a furnace. The presence of boron introduced kinks into the nanotubes and helped form strong, covalent bonds between them, which led them to form a three-dimensional structure.

NEXT STEPS: The researchers plan a controlled study to test how the sponge compares with other products on the market in remediating oil spills. In addition, they intend to perform toxicity studies to determine the sponge's usefulness for biological applications.

ENERGY

Low-Carbon Cement

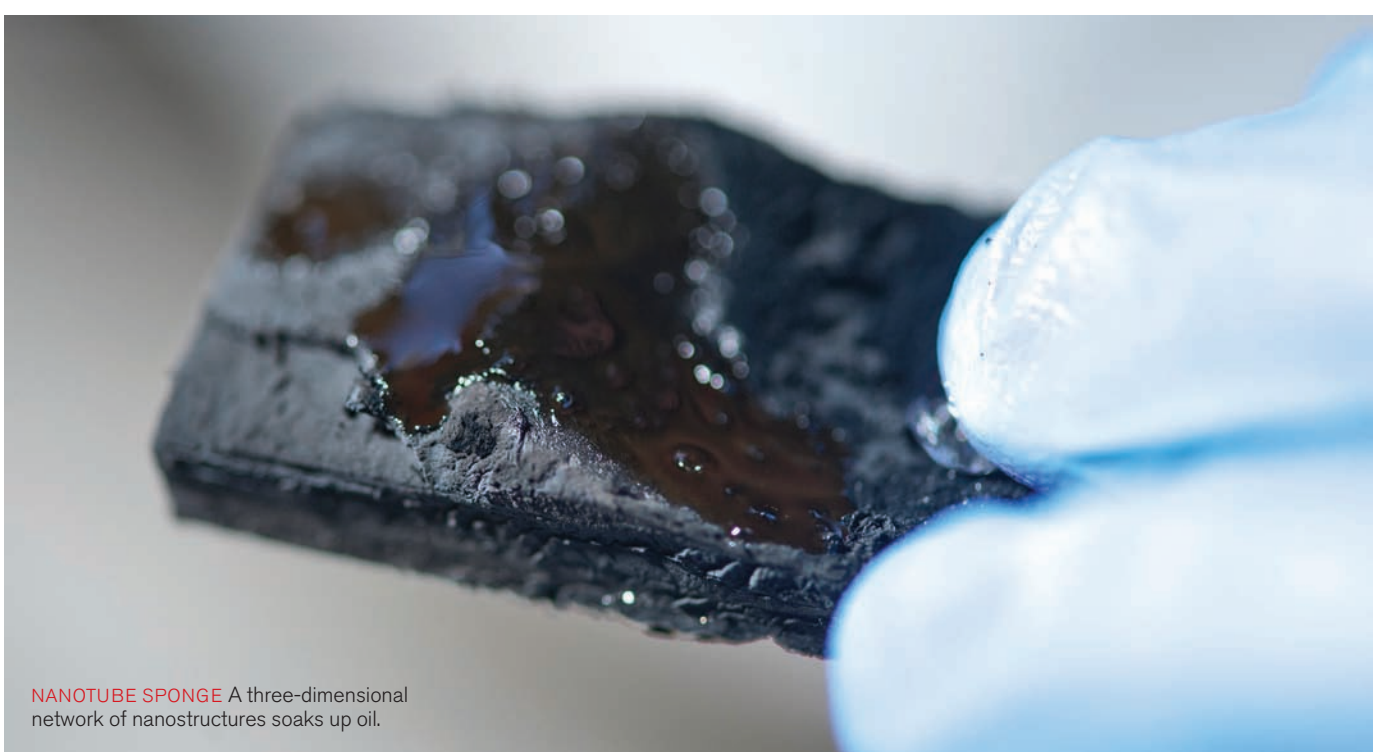
A new chemical process eliminates carbon dioxide emissions from lime production

SOURCE: "STEP CEMENT: SOLAR THERMAL ELECTROCHEMICAL PRODUCTION OF CAO WITHOUT CO2 EMISSION"

Stuart Licht et al.

Chemical Communications, published online April 5, 2012

RESULTS: Researchers at George Washington University have invented a solar-powered process that makes lime from limestone without emitting any carbon dioxide and demonstrated it in a proof-of-



NANOTUBE SPONGE A three-dimensional network of nanostructures soaks up oil.

JEFF FITLOW/RICE UNIVERSITY

concept device. The researchers estimate that the process could cost less than the conventional one.

WHY IT MATTERS: The new process could eliminate a major global source of carbon dioxide emissions. Lime is used to make cement, purify iron, treat soil, and produce glass, paper, sugar, and other things. Cement production alone emits 5 to 6 percent of total man-made greenhouse gases, and most of that comes from producing lime.

METHODS: Rather than simply heating up limestone until it releases carbon dioxide, as in the conventional method, the process uses a combination of heat and electrolysis, which produces lime, oxygen, and either carbon or carbon monoxide, depending on the temperatures used. The researchers built a device that includes three Fresnel lenses for concentrating sunlight. Two of those heat a mixture of lithium carbonate and limestone (calcium carbonate). The third focuses light on a high-efficiency solar cell, which provides the electricity needed to electrolyze the carbonate mixture. High temperatures reduce the amount of electricity needed and cause the lime to precipitate out of the mixture, making it easy to separate.

NEXT STEPS: The device works only when it's sunny, and intermittent operation isn't ideal for an industrial process. The researchers propose using molten salt to store heat, a system used in some solar thermal power plants. That would allow the process to run day and night.

INFORMATION TECHNOLOGY

Seeing in the Rain

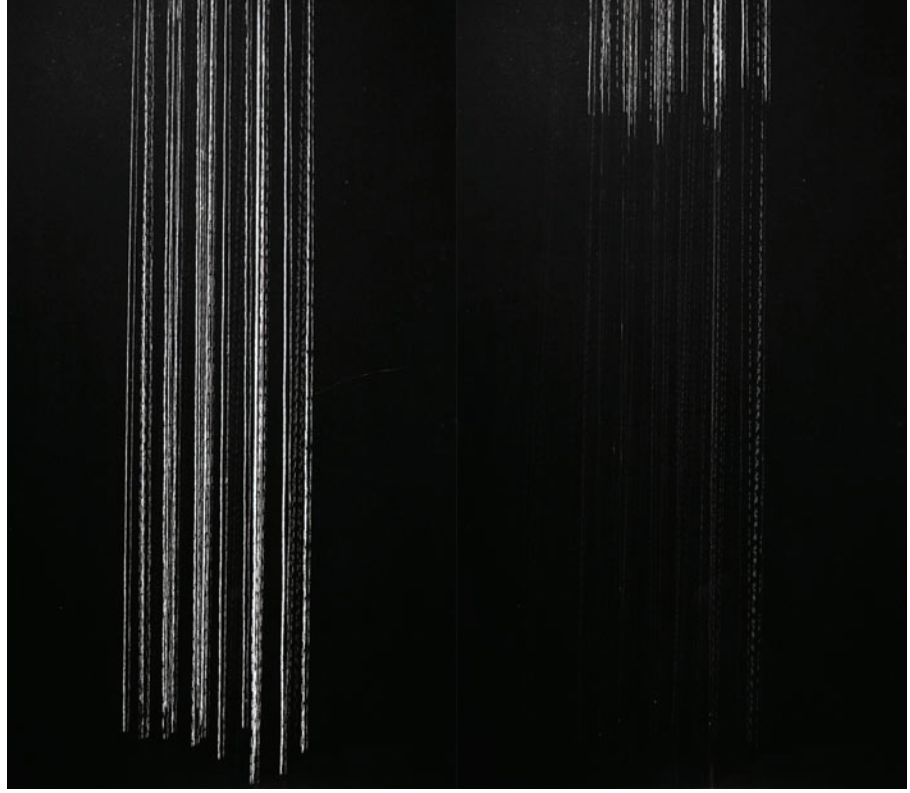
Smart headlights could make difficult driving conditions safer

SOURCE: "FAST REACTIVE CONTROL FOR ILLUMINATION THROUGH RAIN AND SNOW"

Raoul de Charette et al.

IEEE International Conference on Computational Photography, Seattle, Washington, April 27–29, 2012

RESULTS: Researchers at Carnegie Mellon University have written software that allowed a projector to shine light through simulated rain without illuminating the water drops. The system used a camera to predict the downward path of droplets as they entered the top of the projector's beam. Then software directed the projector to selectively black out its beam to avoid the droplets as they fell. In one test, the system could avoid lighting up 84 percent of the droplets.



BLINDING RAIN On the left, light reflects off falling drops of water. On the right, droplet-tracking software helps eliminate that glare.

WHY IT MATTERS: The experiment suggests that future lighting systems for cars could reduce glare reflecting off falling raindrops or snowflakes. Those reflections often distract drivers and can lead to accidents.

METHODS: The researchers paired a high-speed monochrome camera and an off-the-shelf projector. They used a mirror to allow the camera to view the scene in front of the projector from the perspective of its lens. This makes it easier for the software to predict what the projector needs to do to avoid the water drops, since no correction is needed for perspective and viewpoint. They also wrote tracking algorithms that could speed up detection of the droplets.

NEXT STEPS: For such a system to be practical, headlights would need to be based on LEDs, as they already are in some cars today. Arrays of LEDs would allow fine control of a headlight's beam, mimicking the effect of a projector. The system also needs to be faster to be able to handle raindrops approaching a car as it travels at high speeds. The researchers anticipate that cameras, LED light sources, and a processor could eventually be built on the same chip, allowing such a system to sense and react to falling drops extremely quickly.

Sound-Based Gesture Control

Any computer can be controlled with the wave of a hand

SOURCE: "SOUNDWAVE: USING THE DOPPLER EFFECT TO SENSE GESTURES"

Desney Tan et al.

ACM SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, May 5–10, 2012

RESULTS: Software developed by researchers at Microsoft and the University of Wash-

ILLUMINATION AND IMAGING LAB, CARNEGIE MELLON UNIVERSITY

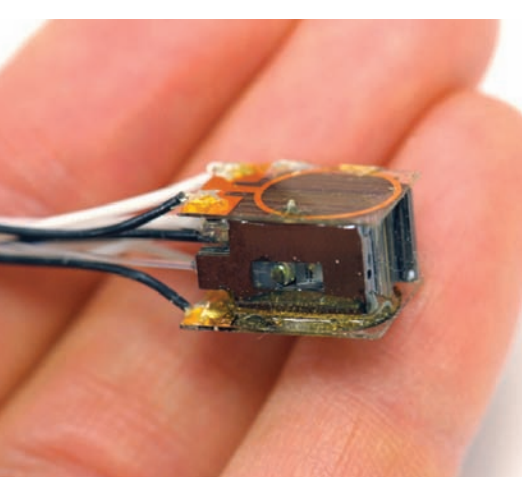
ington uses a computer's speakers and microphone to sense arm gestures and other movements of a person's body. The speakers emit a high-pitched tone between 18 and 22 kilohertz, inaudible to most people, and the microphone picks up sound reflections so the software can analyze them. The researchers showed that a hand wave can be used to scroll through a document or flip through a photo album. The computer can also sense when a user walks away and switch into a low-power state.

WHY IT MATTERS: Devices that use cameras or accelerometers to sense movements, such as Microsoft's Kinect and Nintendo's Wii, demonstrate that gestures can be a useful, powerful, and fun way to control a computer. Gesture control could become more widespread if it could be used without a special camera or hand-held sensor.

METHODS: The researchers programmed the software to analyze reflected sound for several clues that help it recognize a person's gestures. It makes use of the Doppler effect to determine the direction of movement. The researchers also designed a set of hand gestures that could be readily distinguished using those signals, and the software was shown to work reliably on several desktops and laptops with different sound hardware.

NEXT STEPS: The researchers plan to develop more sophisticated mathematical techniques to allow recognition of a wider range of gestures. They also hope to make a version of the software for mobile devices; preliminary tests show that the same approach should work. The accuracy of detection could potentially be improved by making use of the multiple speakers and microphones on some devices to emit and detect more complex tones and reflections.

MIND METER A rubidium-filled sensor detects the magnetic fields of brain waves.



BIOMEDICINE

Compact Brain-Wave Sensor

A mini-magnetometer could inexpensively detect brain injury

SOURCE: "MAGNETOENCEPHALOGRAPHY WITH A CHIP-SCALE ATOMIC MAGNETOMETER"

Svenja Knappe et al.

Biomedical Optics Express 3(5): 981–990

RESULTS: A prototype sensor the size of a sugar cube can measure the magnetic fields produced by electrical activity in the brain, report researchers at the National Institute of Standards and Technology in Boulder, Colorado, and their colleagues.

WHY IT MATTERS: Commercial devices based on the new technology may prove useful for detecting changes in brain behavior caused by brain injury. Such devices could be smaller, cheaper, and more portable than MRI or CT scan machines or conventional brain-wave detectors, which require bulky cooling systems filled with potentially dangerous coolants such as liquid helium. The researchers say the new devices, if mass-produced, could be affordable even for high-school football teams, which could use them to check for brain injury after games. Eventually, the researchers say, they might be used to detect signals from the brain that could be used to control prosthetics.

METHODS: Researchers filled a small cube with gaseous rubidium, which absorbs light differently depending on the strength of the magnetic field it's exposed to. Optical fibers attached to the cube shine lasers into the rubidium and detect the light transmitted through it. In a magnetically shielded room, the team measured the electrical fields produced by subjects wearing the sensor.

NEXT STEPS: The researchers believe that better optics could make the sensor as sensitive as the bulky standard devices. In addition to improving the optics, they plan to combine as many as 100 sensors into one device to help them pinpoint the origin of magnetic fields.

Dividing Cancer

Newly identified differences between breast tumors could help doctors tailor treatments

SOURCE: "THE GENOMIC AND TRANSCRIPTOMIC ARCHITECTURE OF 2,000 BREAST TUMOURS REVEALS NOVEL SUBGROUPS"

Samuel Aparicio et al.

Nature, published online April 18, 2012

RESULTS: Researchers identified 10 types of breast cancer by measuring the genetic differences between tumors.

WHY IT MATTERS: Identifying types of breast cancer could help doctors provide more accurate prognoses. It might also lead to improved treatments. Drugs that aren't effective for the general patient population might prove effective for patients with certain types of breast cancer. By grouping the tumors into types, the researchers were able to identify a new class of patients who might benefit from an existing treatment.

METHODS: The researchers studied nearly 2,000 breast tumor samples. They screened for abnormal parts of each tumor's genome using a technique called DNA hybridization, which enabled them to efficiently examine the DNA and the molecular products of genes in each sample. The team then used a type of mathematical analysis to group similar tumors according to these genomic abnormalities.

NEXT STEPS: The international team, which is based in part at the University of Cambridge and the University of British Columbia, is currently sequencing the genomes of some of the tumors to build a more complete picture of the genomic changes in breast cancer. tr

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27 years ago

Reshaping the Human Species

A bioethicist wondered whether fertility technologies might lead to a new and "improved" *Homo sapiens*.

By TIMOTHY MAHER

"A revolution is under way in human reproduction that is comparable in many ways to the revolution in physics that produced the atomic bomb," wrote Peter Singer, the noted ethicist and philosopher, in the pages of *TR* in February 1985 *("Technology and Procreation: How Far Should We Go?")*. The revolution was the new wave of fertility technology, which seven years before had resulted in the first human baby conceived outside the womb. Singer felt that in vitro fertilization and other advances, like gene therapy, might "someday give us the power to reshape the human species itself."

Taken in itself, IVF may seem nothing more than a means of helping some infertile women become pregnant. But it opens the door to an avalanche of technologies that could be far more controversial: the freezing of human embryos for research use, the donation of an embryo from one woman to another, surrogate motherhood, sex selection, gene therapy for inherited diseases ...

Not all of Singer's predictions turned out to be accurate; genetic engineering of human traits, to name one potential technology he cited, isn't close to happening. But his essay is a reminder of the ethical angst created by the fertility breakthroughs of the time. To ethicists such as Singer, then head of the Centre for Human Bioethics at Australia's Monash University and now a professor at Princeton and the University of Melbourne, the dawning era of biotechnology seemed full of unknown dangers. "Should we tinker with the human gene pool?" he asked. "If so, in what way?" The new techniques, he wrote, "may even allow us to select for desirable traits as well as against undesirable ones":

This could be done by producing several embryos, identifying their genetic characteristics, and then implanting the most desirable embryo. Eventually, it may even be possible to modify the genetic properties of an embryo before implantation to eliminate defects and build in desirable qualities.

As he was writing, doctors were preparing to use gene therapy to treat a brain disorder called Lesch-Nyhan syndrome (the attempt would be unsuccessful, it turned out). The treatment involved removing bone marrow cells from affected children, genetically altering the cells, and injecting them back into the patient. A logical next step, Singer wrote, would be to use the therapy to treat genetic defects in the womb. And if major defects could be cured, why not minor ones?

In time, we may even decide to build in positive modifications. After all, natural selection has left ample room for improving the human race. And the ethical line between eliminating defects and making positive modifications is difficult to draw. If we learn how to affect intelligence, should we stop short at eliminating mental deficiency? If we eliminate abnormally depressive personalities, would it be wrong to try to produce people who tend to be a little more cheerful than most of us are now? If we eliminate tendencies toward criminal violence, might we not build just a little more kindness into the human constitution?

Singer thought we needed a new system of ethics to deal with our new capabilities. What future human beings might do with technology was anybody's guess, but in his mind it was better to think about all the possibilities in advance. (Some countries have tried to limit those possibilities by law: Germany and Norway ban egg donation, while France and Italy deny IVF to single women and gay couples.) Singer saw no problem with a couple using an egg donor if the woman had a genetic defect. But who defined what a "defect" was?

What if the defect is very minor? What if there is no defect at all, but the couple wants a donor egg or sperm from a male or female friend whose intelligence or beauty they consider superior to their own? A California sperm bank is already offering selected women the sperm of Nobel Prize–winning scientists.



Singer noted that some people feared a darker outcome. If we could make ourselves smarter or more beautiful, they mused, a government might be just as capable of using genetic modifications to make us docile. Here, at least, he felt we had nothing to worry about.

If we have succeeded in keeping our freedom in the age of television, snooping devices, and computers, we should be able to cling to it when we have the means to manipulate genetic traits as well. The technical ability to suppress liberty has been with us for a long time. It is our determination to prevent our rulers from exercising this ability that has kept us free. tr

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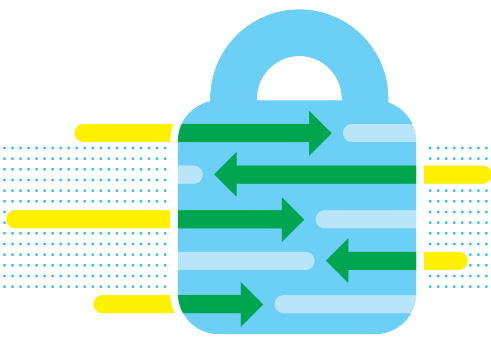
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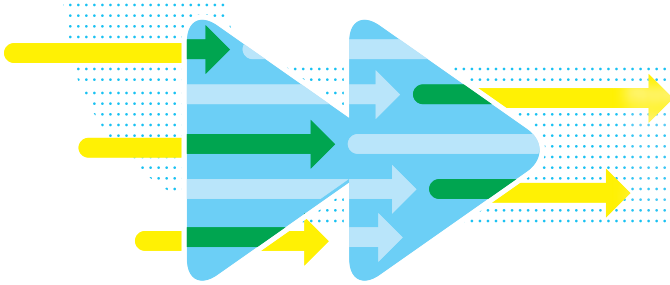
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